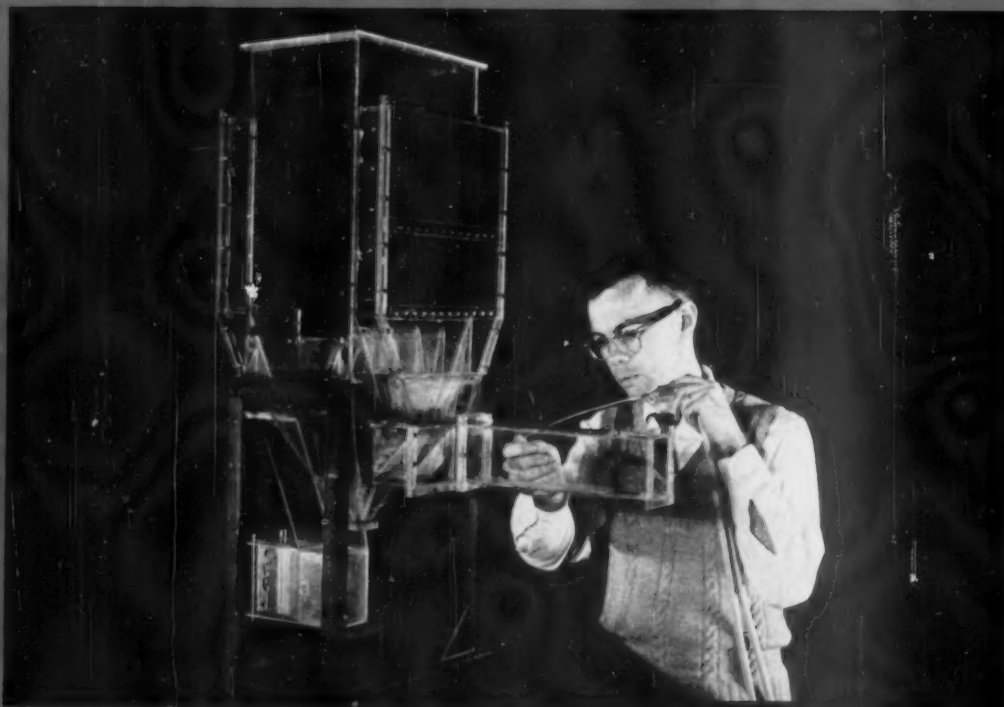


# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

**June 1958**



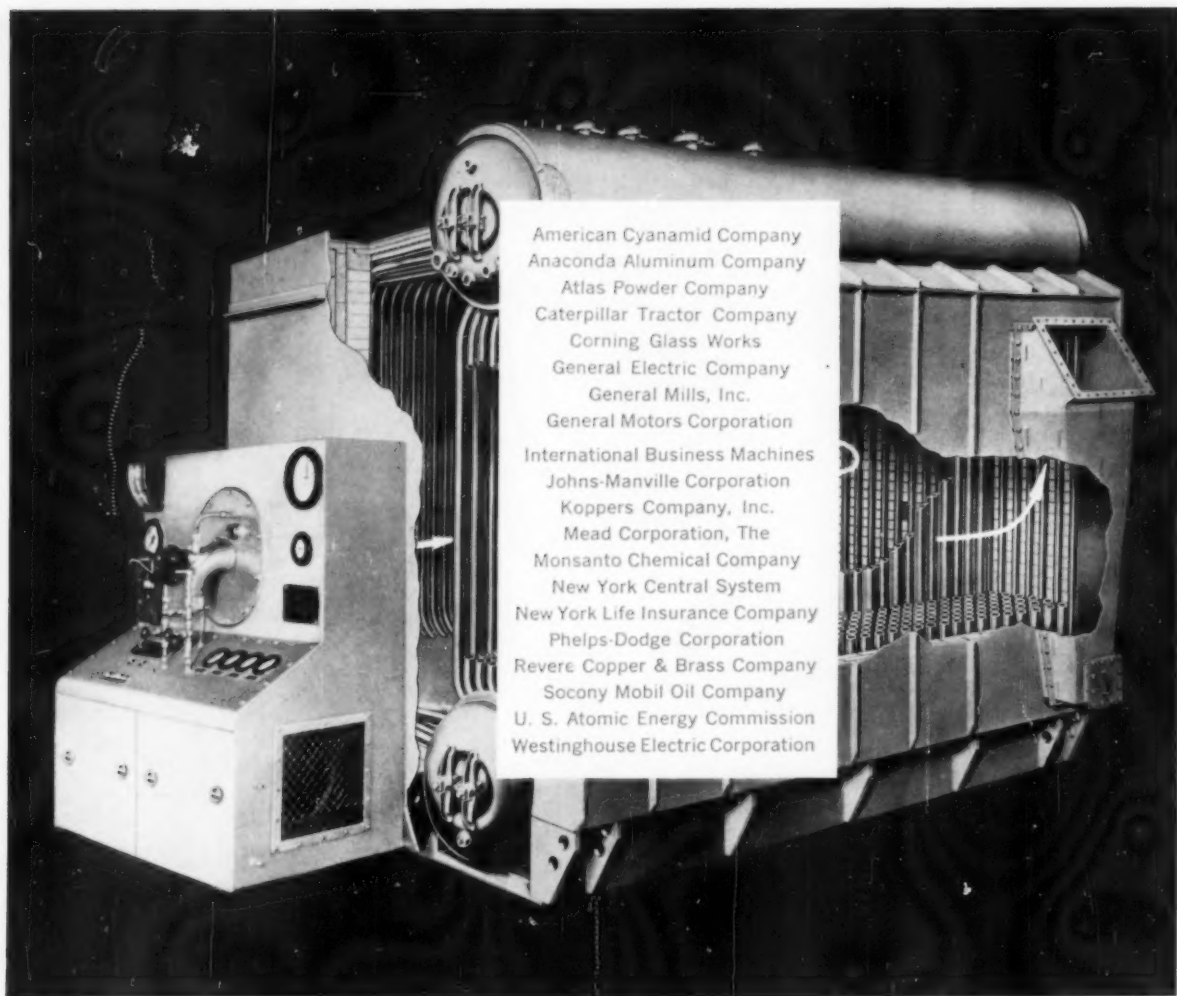
Plastic models such as the above Research-Cottrell one offers industry visual checks on dust collector operation (See pp 41)

**Control of the Sulzer Monotube**

**Plastic Models Improve Dust Collectors**

**Film Boiling On Boiler Surfaces**

**The Fight Against Fuel Clogging**



## LEADING INDUSTRIALS CHOOSE THE VP

Not only do many of the nation's leading industrial companies — such as those listed above — buy VP Boilers, but also a long list of smaller companies and institutions have VP package boiler installations.

The choice of the "big" companies, however, has some special significance. They buy boilers frequently — therefore, their experience is always up to date. They buy them in all capacities large and small. Their requirements justify employment of highly qualified engineering specialists —

both staff men and outside consultants. Thus, they have the breadth of experience and the expert guidance requisite to making the soundest equipment selections.

So — if you are in the market for boilers in the capacity range from 4,000 to 50,000 pounds of steam per hour, we submit that you can buy with confidence the boiler chosen by so many of the nation's largest industrialists — the C-E Package Boiler, Type VP. A new descriptive catalog, VP-3, is just off the press. Write for your copy.

### COMBUSTION ENGINEERING

Combustion Engineering Building • 200 Madison Avenue, New York 16, N. Y.



C-1308

# COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 29

No. 12

June 1958

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COMBUSTION published its annual index in the June issue and is indexed regularly by Engineering Index, Inc. and also in the Applied Science & Technology Index.

The magazine is now reproduced and distributed to libraries on microfilm by University Microfilms of Ann Arbor, Michigan.

ROBERT D. TAFT  
*Business Manager*

JOSEPH C. McCABE  
*Editor*

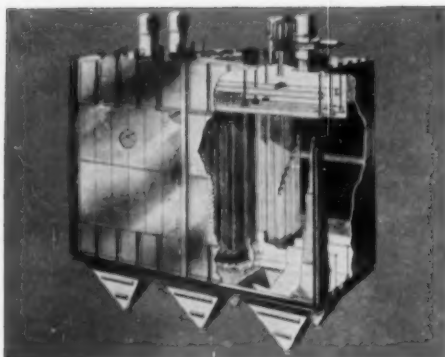
GLENN R. FRYLING  
*Associate Editor*

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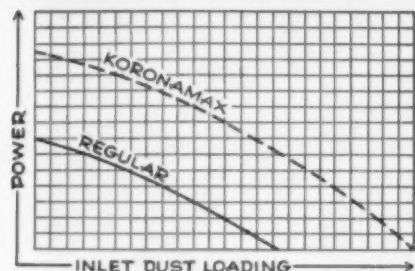
Joseph V. Santry, Pres.; Charles McDonough, Vice-Pres.; Otto Strauss, Treas.; Thomas A. Ennis, Secy.  
COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up; and to consulting engineers in this field. To others the subscription rate, including postage, is \$4 in the United States, \$5.50 in Canada; and \$8 in Latin America and other countries. Single copies: Domestic, 40 cents; Foreign 60 cents plus postage. Copyright 1958 by Combustion Publishing Company, Inc. Publication Office, Easton, Pa. Issued the middle of the month of publication.  
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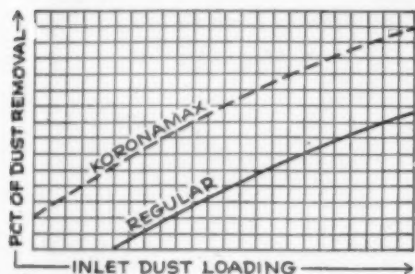
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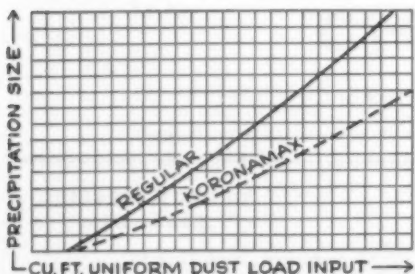
## Another Koppers Exclusive in ELECTROSTATIC PRECIPITATION



**INCREASED POWER**—The evenly spaced discharge points of "Koronamax" Electrodes reduce the arc-over tendency and permit increasing power input.



**HIGHER EFFICIENCY**—Replacement of regular electrodes with "Koronamax" Electrodes allows higher power input — greatly increased efficiency.



**SMALLER SIZE**—In new installations desired efficiency may be obtained with smaller unit when "Koronamax" Electrodes are used.



CONVENTIONAL ELECTRODES



"KORONAMAX" ELECTRODES

## "KORONAMAX" ELECTRODES increase efficiency and capacity of electrostatic precipitators

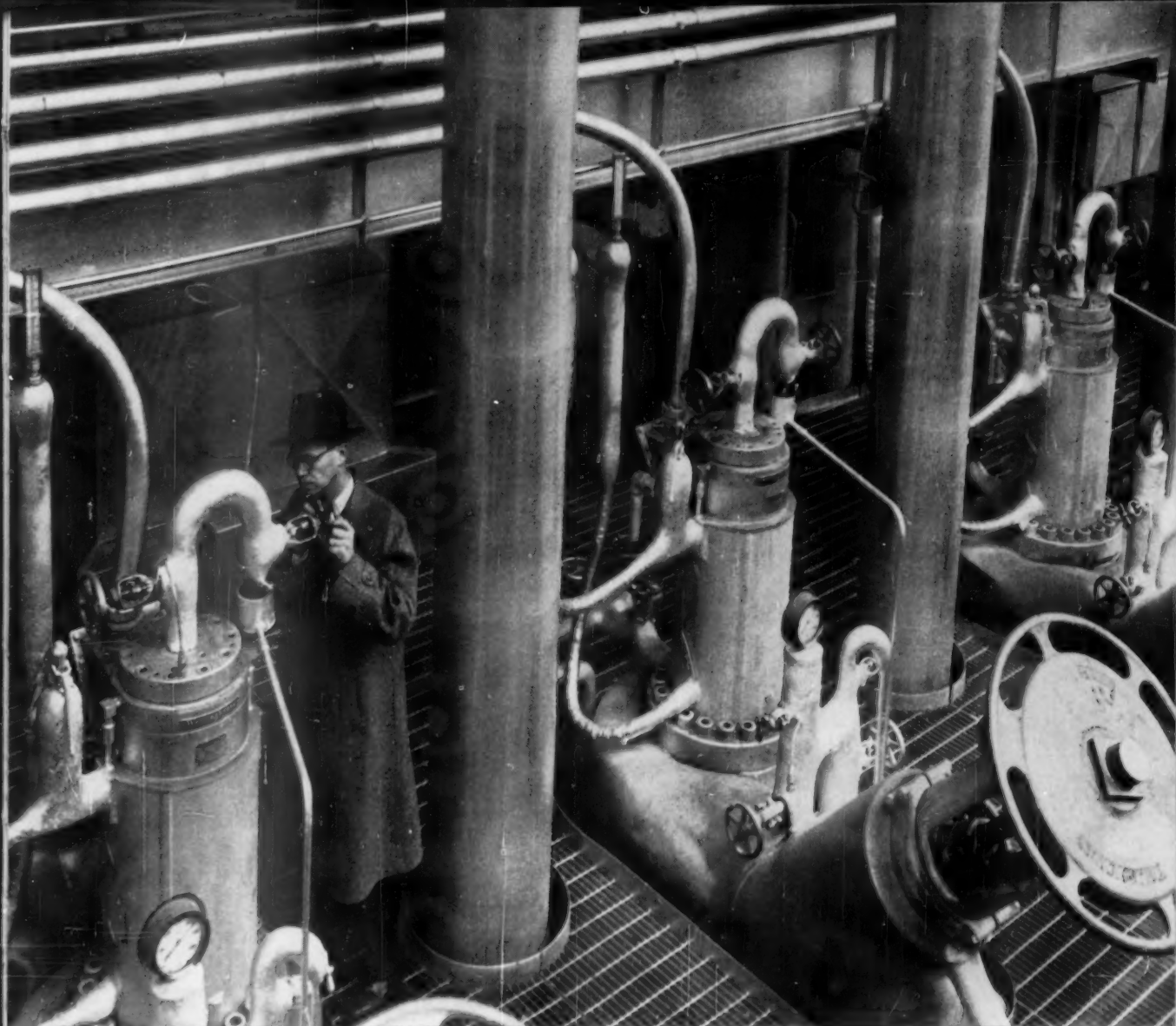
"Koronamax" Electrodes developed by Koppers are now in service in several different applications and their *controlled* corona discharge has resulted in greatly increased capacity and efficiency. This unique type of precipitator electrode may solve your gas cleaning problem.

Koppers' experience, constant research and extensive field testing have led to this important advance in precipitator design. Check with Koppers to see if "Koronamax" Electrodes can help you get top precipitator efficiency. For more information, write: KOPPERS COMPANY, INC., 4406 Scott Street, Baltimore 3, Md.



## ELECTROSTATIC PRECIPITATORS

Engineered Products Sold with Service



## Westinghouse canned motor-pumps specified for KP&L outdoor installation

The Kansas Power and Light Company recently increased the capacity of its Tecumseh Station with the addition of a 75,000-kw outdoor unit. This new addition, the most efficient in the plant, will operate day and night as the base load unit. To insure reliability, Westinghouse canned motor-pumps were specified for the Combustion Engineering Inc. controlled circulation boiler.

Westinghouse pumps were selected because: they have been proven for long-term continuous operation in many other installations; the zero-

leakage feature eliminates injection water sealing. Two pumps provide the required boiler water circulation to deliver 635,000 pounds of 1000°F steam at 1800 psi. A third Westinghouse pump is kept on hot standby. All three are rated at 4070 gpm, 1958 psi, 615°F.

For further information on the tested and proven Westinghouse canned motor-pumps, contact your Westinghouse sales representative, or write: Westinghouse Electric Corporation, Atomic Equipment Dept., P.O. Box 217, Cheswick, Penna.

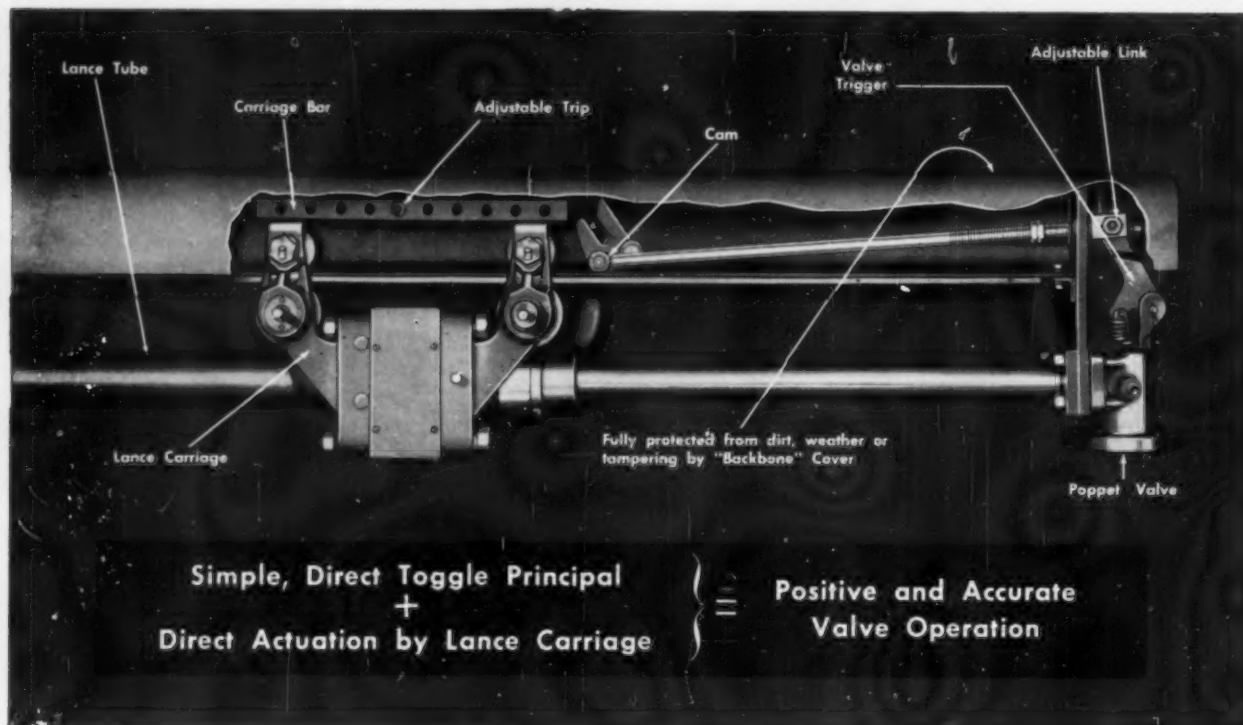
J-57019

YOU CAN BE SURE...IF IT'S

# Westinghouse



# MECHANICALLY OPERATED



SERIES 300 IK—LONG RETRACTING BLOWER

## OTHER ADVANTAGES OF SERIES 300 IK BLOWERS

- Backbone and Protective Cover
- Compact, Accessible Electric Power and Control Terminal Facilities
- Front End Single-Motor Drive
- Nozzle-Sweep-Every-Inch Cleaning Pattern
- Improved "Type A" Nozzle
- Positive Gear Carriage Drive
- Single Point Outboard Suspension
- Oversize Lance (Step-Tapered for Extra Long Travel)
- Auxiliary Carriages for Extra Long Travel
- Designed for Quick, Easy Servicing

*No other blower gives you all these advantages.*



## DIAMOND POWER SPECIALTY CORP.

LANCASTER, OHIO

*Diamond Specialty Limited, Windsor, Ontario*

# POPPET TYPE VALVE

(WITH ADJUSTABLE PRESSURE CONTROL)

additional important features of the

*New*



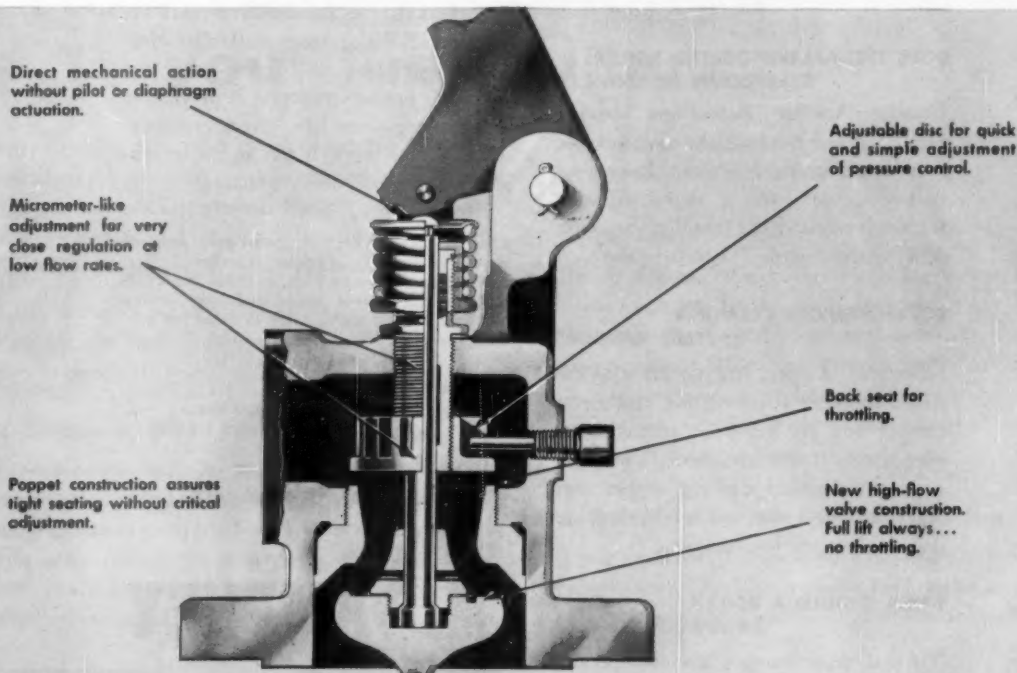
Series 300 IK  
LONG RETRACTING BLOWER

This valve was adopted for the new Series 300 IK because long experience has proved it the most satisfactory of all designs for severe blower service. More than 300,000 of this basic design are in use on various Diamond Blowers and have established notable service records. A recent improvement is more streamlined flow contours that permit higher flow rates with less pressure drop.

The direct mechanical linkage for actuating the valve offers the advantages of greater reliability and

safety . . . in addition to more accurate control. Numerous other important features of the Series 300 IK are listed at the bottom of the left hand page. These are the reasons why this blower is establishing a new standard of efficiency, economy and dependability in cleaning heating surfaces that require a long retracting blower.

Bulletin 2111V tells much more about the Series 300 IK; ask your local Diamond office or write directly to Lancaster for a copy.



**FULL LIFT AND FULL OPENING OF VALVE AT ALL TIMES. No throttling at main seat. ALL throttling for pressure control is between back seat and adjustable disc.**

... ANSWERING YOUR QUESTIONS ABOUT

## *Apexior Number 1 for boilers*

®

### **HOW MUCH CLEANING IS NECESSARY BEFORE APEXIOR-COATING?**

A surface no cleaner than good operating practice demands is all the foundation needed for Apexior Number 1—the coating that ever after holds steel at newly cleaned efficiency.

### **HOW DOES THE DAMPNEY TEST KIT SERVE?**

By saving man-hours that might be expended needlessly. A quick, three-step check tells when cleaning has delivered just-right surfaces, prepared neither less nor more than necessary.

### **DOES THE APEXIOR-COATED BOILER STAY CLEAN IN SERVICE?**

Because Apexior discourages deposit formation and bonding, the coated boiler needs less cleaning, less often. Inspection is easier, too—for a sound Apexior surface reveals itself readily, assuring equally sound steel  $2\frac{1}{2}$  mils beneath.

### **DOES CHEMICAL CLEANING AFFECT APEXIOR?**

In no way. Rather, Apexior takes on the added function of preventing acid-metal contact and the resultant attack, however slight, that might occur. Those engaged in chemical cleaning report that Apexior speeds the process by keeping deposits few and less tenacious.

### **WHEN SHOULD A BOILER BE APEXIOR-COATED?**

To seal water-contact surfaces permanently at highest efficiency and take them

safely through the initial shake-down period, a new boiler should be Apexior-coated immediately after erection; an operated boiler, immediately after cleaning.

### **IS APEXIOR BOILER COATING DIFFICULT?**

Not at all. Apexior is brush applied—by hand to drums and flat areas; by air-driven tube turbine, brush-equipped, to tube interiors. Application is regularly made by plant crews with or without initial Dampney supervision.

### **HOW LONG DOES APEXIOR LAST?**

A conservative estimate: Five years before retouching or renewal. Under ideal conditions: Ten to twelve . . . for Apexior's primary function is preventive maintenance—its life, directly proportional to the work it has to do in supplementing good boiler practice.

*This message—one of a series—presents more reasons why Apexior Number 1, first used inside boilers in 1906, is today manufactured in the United States and four foreign countries to meet world-wide demand for protection of*

- boiler tubes and drums
- evaporators
- deaerating and feedwater heaters
- steam turbines

### **MAINTENANCE FOR METAL**

**D** THE  
**DAMPNEY**  
C O M P A N Y

HYDE PARK, BOSTON 36, MASSACHUSETTS



This Bailey Control System helps cut fuel costs on a 70,000 lb per hr capacity 125 psi boiler in an industrial plant. Control drive in foreground regulates stoker.

## How Bailey stretches your fuel dollar...

You can wring more energy out of a dollar's worth of fuel when you are getting optimum performance from your steam plant equipment. You get peak performance when Bailey Meters and Controls are on the job. They increase your plant efficiency.

Bailey is the choice of virtually all the most efficient plants on the Federal Power Commission's heat rate report. Here's why:

### 1. Complete Line of Equipment

You can be sure a Bailey Engineer will offer the right combination of equipment to fit your needs. Bailey manufactures a complete line of standard, compatible pneumatic and electric metering and control equipment that has proved itself. Thousands of successful installations involving problems in measurement,

combustion, and automatic control are your assurance of the best possible system.

### 2. Experience

Bailey Engineers have been making steam plants work more efficiently for more than forty years. Veteran engineer and young engineer alike, the men who represent Bailey, are storehouses of knowledge on measurement and control. They are up-to-the-minute on the latest developments that can be applied to your problem.

### 3. Sales and Service Convenient to You

There's a Bailey District Office or Resident Engineer close to you. Check your phone book for expert engineering control on your steam plant control problems.

AI32-1



*Instruments and controls for power and process*

**BAILEY METER COMPANY**

1025 IVANHOE ROAD • CLEVELAND 10, OHIO

In Canada — Bailey Meter Company Limited, Montreal

*First in water conditioning*

# What type deaerator best suits your requirements?

*These six bulletins will give you the answer.*

Starting with the bulletin on Why and How of Deaeration, you are introduced to the problems encountered and advantages of the various types of deaerators.

Other bulletins cover the specific application of the Jet-Tray, Tray Type, Atomizing Deaerator, Surface Type Deaerating Hot Water Heater and Cold Water Deaerator.

Regardless of the application you require, you will want these bulletins for your file. Cochrane Corporation pioneered in the field of deaeration and today manufactures every type of deaerator to meet any specific application, as well as a complete line of water conditioning equipment. This background assures you that guarantees will be met and that whatever your requirements, Cochrane can furnish you with the exact type to fit your needs. Why not write for this series of six bulletins today? Consult Cochrane first on your water conditioning problem.



## Cochrane

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Cochrane Water Conditioning Ltd., Toronto 4; Montreal 1, Canada  
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Pittstown Metal Prods. Div.—Custom built carbon steel and alloy products.



Demineralizers • Zeolite Softeners • Hot Process Softeners • Hot Lime Zeolite Softeners • Dealkalizers • Reactors • Deaerators • Pressure Filters  
Continuous Blowoff Systems • Condensate Return Systems • Steam Specialties

# THE BAYER CO.

MANUFACTURERS OF BAYER SOOT BLOWERS

*For Highest First and Final Value*

... BUY BAYER!



## BAYER *Balanced Valve* SOOT CLEANER

Bayer's single-chain design compels perfect in-step operation of valve and element. Operation is positive, definite, assuring a full flow of steam for efficient cleaning.

When the operator pulls chain, the cam-actuated, quick-action balanced valve is opened. By continued pulling of the chain, worm drive slowly rotates element over cleaning arc. When element reaches end of cleaning arc, valve automatically closes.

Minimum steam consumption—low maintenance. Every detail is engineered, built for long life, efficient performance at high temperatures and high pressures.

More than 30,000 boilers are Bayer equipped. More than 45 years' successful, specialized experience assures you investment economies in Bayer equipment.

**QUALIFIED LOCAL ENGINEERING SERVICE**—Your Bayer representative is an experienced engineer, well qualified to take care of any service needs in connection with Bayer Soot Cleaners. He is available when you call upon him and will gladly render any service required.

All These Mechanical and Operating Advantages are available in

### The BAYER *Balanced Valve* SOOT CLEANER

1. Sound engineering, workmanship, and materials of the best.
2. An organization of over 45 years' experience, capable and willing to render service at all times.

**SINGLE CHAIN:** Valve and element controlled by a single chain.

**VALVE BODY:** Rugged construction, built to last. Short and ample steam passage giving very small pressure drop.

**ORIFICE PLATE VALVE:** For high pressure service, each head may be controlled by an orifice plate valve through which pressure is adjusted for each individual element.

**STUFFING BOX:** Due to maintenance of perfect alignment on swivel tube, packing needs little attention. Stuffing box is in full view, readily accessible.

**AIR SEAL:** Has machined surface on wall sleeve and spring-held floating seal to prevent air in-leakage.

**HEAD BEARINGS:** There are two main bearings, an outboard and an inboard bearing for the swivel tube to maintain alignment.

**THRUST BEARING:** Ring type thrust bearing takes the load.

**VACUUM BREAKERS:** Two vacuum breaker air valves, or one valve and a signal whistle above each valve, to prevent suction of boiler gases into valve and piping.

**ELEMENT OPERATION:** With the Bayer element operation, balanced valve is opened just as element rotates, giving FULL pressure over entire cleaning arc. Full steam pressure insures thorough cleaning. Balanced valve saves wear of valve parts. With any type of poppet valve, this is important...ask any operator.

**BLOWING ARC:** Valve cams automatically regulate cleaning arc.

**REDUCTION GEARS:** 24 to 1 gear ratio gives slow rotation for good cleaning.

**FLANGED PIPE CONNECTION:** Operating head is connected to supply pipe by flanges and through bolts, or high tensile studs and nuts.

THE BAYER CO.  
St. Louis, Mo.

# Ford shifts



# to coal for low-cost steam

**Coal proves economical and easily available  
for steam generation at Ford's Louisville plant**

Assembly Plant #2, Ford Division—Ford Motor Company, Louisville, Ky., was constructed in 1954. Because of the importance of steam for process work and heating, Ford's engineering department—working with the consulting firm of Albert Kahn Associated Architects and Engineers, of Detroit—conducted a fuel survey before the power house was designed. Object: to find an economical and efficient fuel.

Result: *coal* is used because of its *continuous* plentiful supply and advantageous price. Today this advanced coal-burning installation produces a reliable supply of low-cost steam. Only routine maintenance has been required and the cleanliness and general efficiency of this steam plant are considered among the outstanding features of its operation.

## **Facts you should know about coal**

You'll find that bituminous coal is not only the lowest-cost fuel in most industrial areas, as in the case of Ford's Louisville plant, but up-to-date coal burning equipment can give you 15% to 50% more steam per dollar. Today's automatic equipment can pare labor costs and eliminate smoke problems. And vast coal reserves plus mechanized production methods mean a constantly plentiful supply of coal at stable prices.

## **Technical advisory service**

To help you with industrial fuel problems, the Bituminous Coal Institute offers a free technical advisory service. We welcome the opportunity to work with you, your consulting engineers and architects. If you are concerned with steam costs, write to the address below. Or send for our case history booklet, complete with data sheets. You'll find it informative.

## **Consult an engineering firm**

If you are remodeling or building new heating or power facilities, it will pay you to consult a qualified engineering firm. Such concerns—familiar with the latest in fuel costs and equipment—can effect great savings for you in efficiency and fuel economy over the years.

## **BITUMINOUS COAL INSTITUTE**

Dept. C-06, Southern Building, Washington 5, D. C.

Firing aisle, shows Boiler #1 in right foreground. This is 60,000 lb/hr unit, using a two unit spreader stoker; Boilers #2 and #3 have capacity of 120,000 lb/hr and use four feeders. All three boilers are by Wickes Boiler Co., Type R, operating at 125 psi, 350 degrees F, fired by American Engineering "Perfect Spread" stokers.



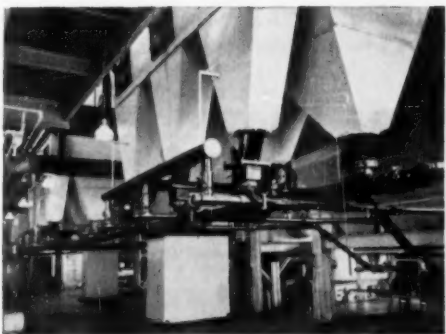
Showing National Car Shaker being used to expedite emptying of cars. Dustless ash removal system in background.



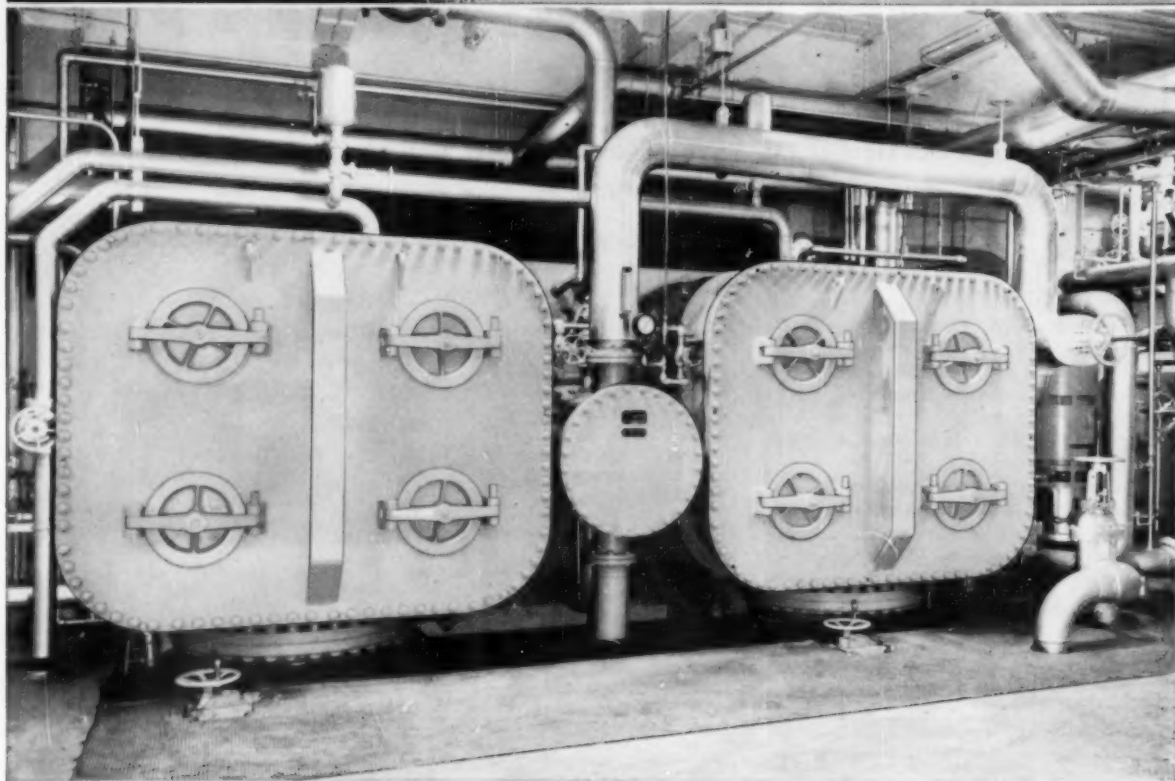
Beaumont Birch Steam Vacuum System draws ashes through pipes to outside ash silo for removal. View is at basement level, below boiler room floor. Coal handling system also by Beaumont Birch Co.



Mechanical dust collectors are by Prat-Daniel Corp. Fly ash handling system removes ash from collectors and boiler passes.



PROGRESS IN POWER  PROGRESS IN HEAT TRANSFER EQUIPMENT



## NEW-DESIGN CONDENSERS SAVE SPACE AND **MONEY**

Steam generation of electricity has made tremendous progress in the last 25 years because of the ever-increasing efficiency of the equipment used.

A power equipment manufacturer with many "firsts" to its credit, Yuba is continually designing, among other equipment, condensers with low head room to save much-needed space. This advancement is illustrated above in the photograph of a rectangular shape condenser for the Suwanee River Plant of the Florida Power Corp.

A low pressure heater is installed between the

tube banks to further save plant space, as well as initial cost for foundation and piping. An additional design feature of Yuba condensers is a de-aerating section within the condenser shell which eliminates the main plant de-aerating heater. Maintenance and downtime costs are reduced by welding tubes into tube sheets.

For advanced condenser design, that will save space and money, consult the Yuba Heat Transfer Division, formerly the Heat Exchanger Division of The Lummus Co.

### YUBA HEAT TRANSFER DIVISION

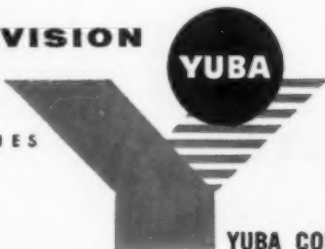
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NEW YORK SALES OFFICE: 530 FIFTH AVENUE  
REPRESENTATIVES IN PRINCIPAL CITIES

*Other Yuba Divisions*

Adsco Division, Buffalo, N. Y.

California Steel Products Division, Richmond, Calif.

Yuba Manufacturing Division, Benicia, Calif.



STEAM SURFACE CONDENSERS  
EVAPORATORS  
STEAM JET REFRIGERATION  
STEAM JET AIR EJECTORS  
FEEDWATER HEATERS  
BAROMETRIC CONDENSERS

YUBA CONSOLIDATED INDUSTRIES, INC.

# Hall Industrial Water Report

VOLUME 6

JUNE 1958

NUMBER 3

## Steel Production at New High

The day is not too far off when we shall be reading headlines like this. And when we do we shall know that again steel manufacturing facilities are being pushed to the limit and that avoiding unscheduled outages is of paramount importance.

Uninterrupted operation requires an effective water treating program whether the plant is a giant or a midget and whether the product is steel or silk stockings. That is why so many plants retain Hall Laboratories to help them avoid and solve problems with boiler water, cooling water, service water, process water and waste water.

## Hard Water in Condensate

When a steel mill installed new boilers the old hot-process, lime-soda softener was retained to treat the make-up water. After a short period, operators were faced with the fact that phosphate consumption was far in excess of what it should have been. Checks showed that the softener was working properly, so hard water had to be entering the system at some other point. But where?

The search for the source of the hard water contamination was finally rewarded with success. In the old power plant, available condensate had been pumped into the raw water inlet line to the softener at a point down stream from the control valve. In the new plant the turbo-blower condensate was pumped into the deaerating heater. The old condensate piping was not removed and was merely extended to the heater. Since less pressure was required to pump the condensate to the new location than to the old, it went to the heater. But along with it went raw water which flowed in reverse through the old condensate piping.

It was easy to eliminate the trouble by blocking the old condensate line after the hard part of tracing down the source had been accomplished by the Hall engineer with the help of the operators.

## Cleaner Waste Water

A foundry clarifies hydro-blast water before reusing it or discharging it to waste. Standard procedure was to use aluminum sulfate as the coagulant with activated silica as a coagulant aid. This produced a water of less than satisfactory quality at a high cost.

The Hall engineer substituted a Hagan Coagulant Aid for the activated silica. This not only produced an effluent of greatly improved clarity but did so with almost 75 percent less aluminum sulfate. An added bonus was the ease of preparing the Hagan Coagulant Aid slurry as compared to the care required in mixing the activated silica sol.

## "Obvious" Diagnosis Wrong

On a routine visit to an eastern steel fabricating plant, Hall engineer J. T. Waldron found the water in the new high-pressure boiler to be badly contaminated with salt. A check on the zeolite treated make-up water showed this was not the source. Then the condensate from the surface condenser was found to be high in chloride. The obvious conclusion was that the condenser was leaking and allowing contamination of the condensate with the salt water used for cooling.

Waldron had been fooled before and was not ready to accept the obvious answer. He looked further and discovered the real trouble. The low-pressure end of the turbine was sealed with steam through a connection at the top of the seal; at the bottom was a drain connected to an eductor activated by salt water. Insufficient steam was being supplied to the seal, so the vacuum in the turbine outbalanced the vacuum produced by the eductor. Salt water accordingly backed up from the eductor through the steam seal into the turbine. More steam to the seal and a little less salt water to the eductor solved the problem.

Correct diagnosis here was indeed fortunate. If the "obvious"

had been accepted the operators would have had an emergency shut-down of the turbine to check the surface condenser. Then they would have been dismayed to find no leaks and no answer to their difficulty.

## Steel Without Spots

The galvanized strip steel from a Pennsylvania mill developed large discolored spots some weeks after shipment. Because of their concern over this serious problem the operating men enlisted the aid of everyone who might be able to help them.

Hall Engineer B. Q. Welder was asked for his opinion. From his experience with metal cleaning, he suspected the rinsing operations. Following galvanizing the strip was spray rinsed with filtered river water, dip rinsed with the same water and then rinsed in a sodium chromate-sodium silicate solution prepared with river water. Welder's opinion was that the solids in the rinse waters were drying on the metal. When a humid atmosphere subsequently produced condensation and solution of the salts, they reacted with the zinc coating, discoloring the metal surface. A confirming factor was the increase in seriousness of the spotting in inverse ratio to the gauge of the strip. Lighter gauge material traveled faster through the equipment and carried out more water.

A condensate rinse was added just ahead of the chromate-silicate rinse and condensate was substituted for river water in preparing the latter solution. The problem was solved.

## Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information on how the Hall System can help you solve your particular water problems, write, wire or call address below.

*Water is your industry's most important raw material. Use it wisely.*

### HALL LABORATORIES

DIVISION OF HAGAN CHEMICALS & CONTROLS, INC.  
HAGAN BUILDING, PITTSBURGH 30, PENNSYLVANIA  
DIVISIONS: CALGON COMPANY, HALL LABORATORIES  
IN CANADA: HAGAN CORPORATION (CANADA) LIMITED—TORONTO

**Hall Laboratories—Consultants on Procurement, Treatment, Use and Disposal of Industrial Water**



## NUCLEAR DIVISION, Windsor, Conn.

Located on a 530-acre site, this plant was completed last year. It contains facilities for all phases of reactor work except the fabrication of heavy components. Research and development facilities include Materials Development, Chemical, Metallurgical, Electronic and Mechanical Laboratories. Now under construction on the site is the country's first nuclear submarine prototype to be built at other than AEC-owned properties.



(ABOVE)—Partial view of Fuel Element Manufacturing Plant at Windsor. This plant includes an 80-foot high building where the intricate job of reactor core assembly is performed.

(BELOW)—Preparing a reactor for test in one of Windsor's two Critical Assembly buildings. Facilities for reactor testing include equipment for chemical analyses, spectrography, spectrometry, destructive and non-destructive tests.



# Ready FOR

On these pages are shown Combustion's facilities for the design, development, manufacture and test of complete nuclear reactor systems, including both light and heavy components. . . . These facilities, fully staffed by scientists and technicians, enable the Company to design and manufacture full-scale nuclear power installations for any requirements—civilian

## COMBUSTION

Combustion Engineering Building

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS;



NUCLEAR BUILDING, Chattanooga, Tenn.

This 520-foot building contains the specially designed equipment required for the manufacture of heavy nuclear components. Extremely close tolerances, fine finishes and surgical cleanliness are requisites in the production of these massive vessels. The reactor vessel for the Shippingport Station of Duquesne Light Company—the country's first full-scale nuclear power plant—was constructed in this building.

## THE ATOMIC AGE

or military. . . . Combustion is also equipped and qualified to serve the nuclear field in the development of Materials, Mechanisms and Processes, and to provide such special services as Safety Consulting, Radiation Surveys, and Chemical and Biological Analyses. Information on these special services is available and will be sent on request.

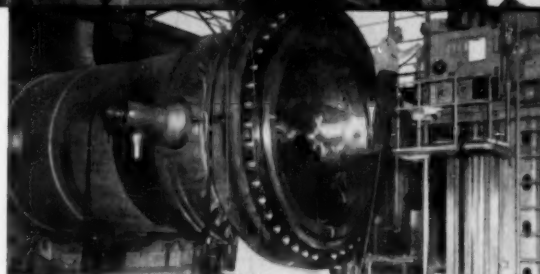
# ENGINEERING

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C-153

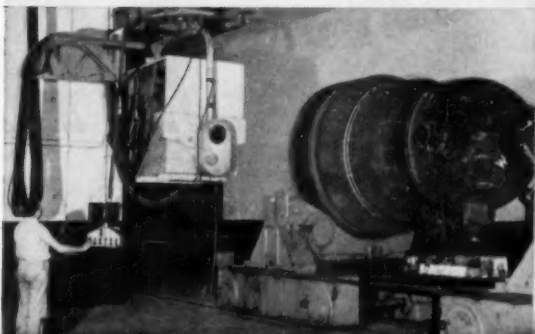


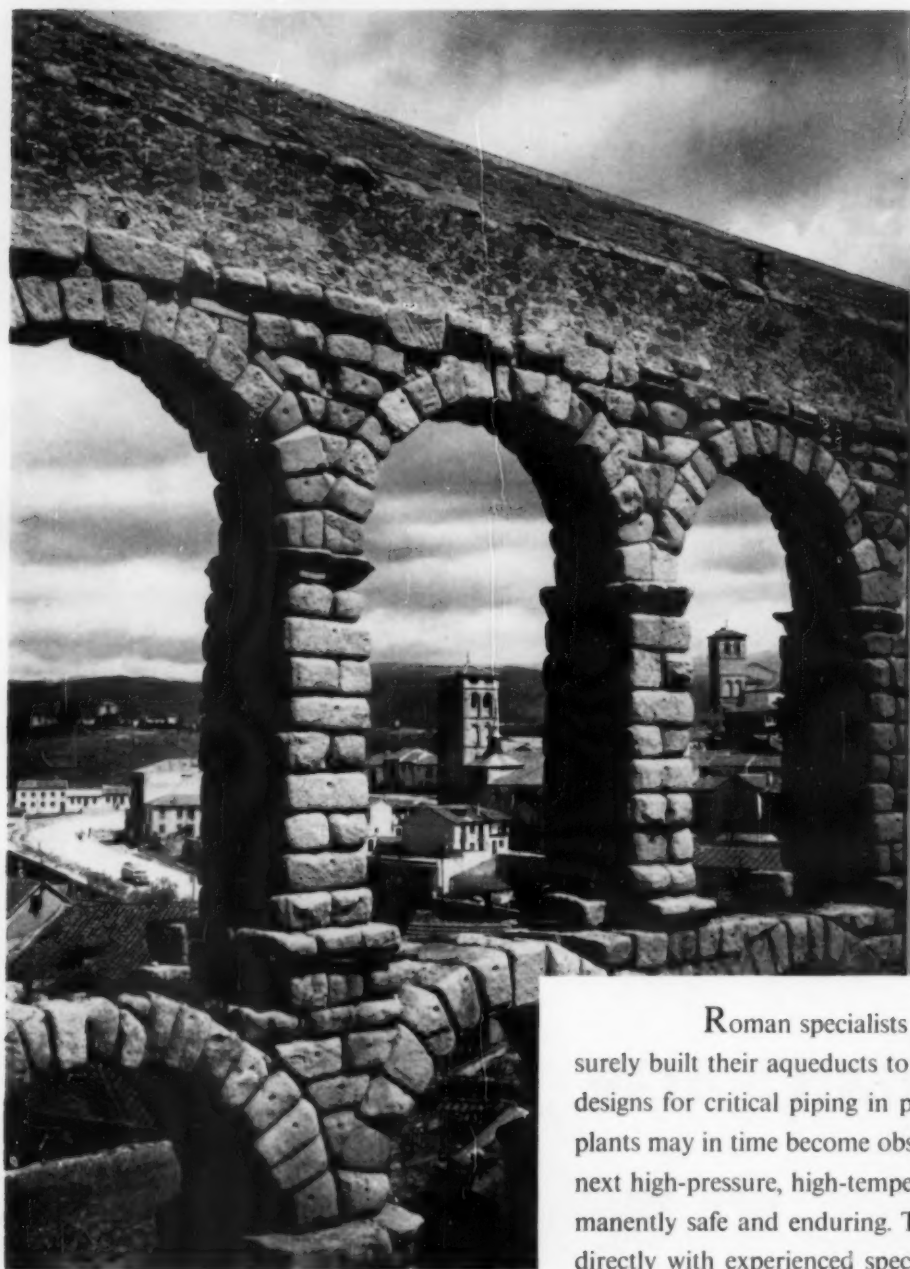
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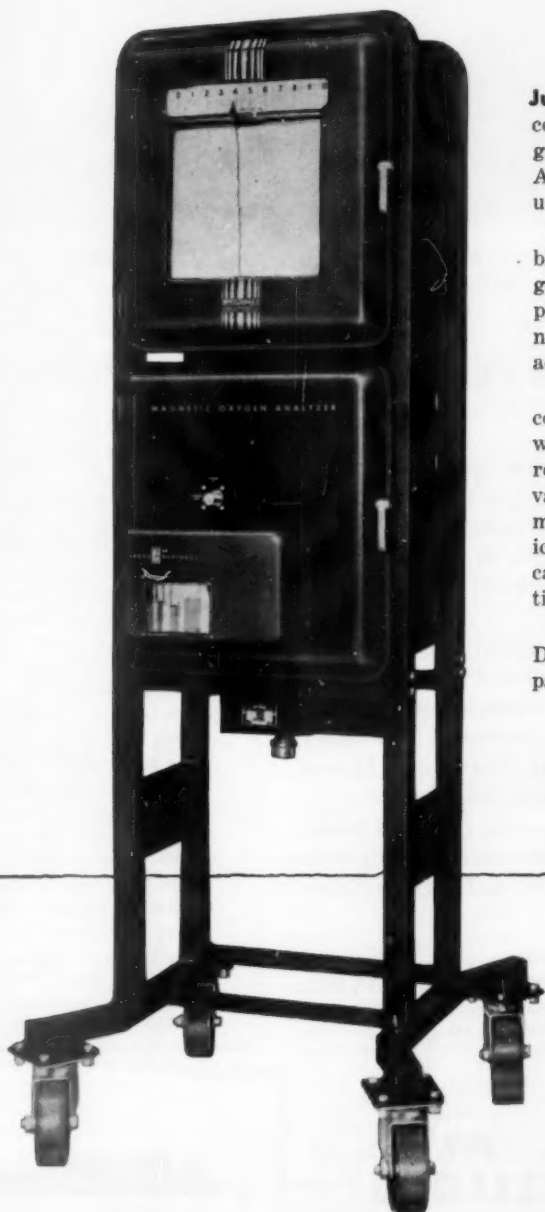
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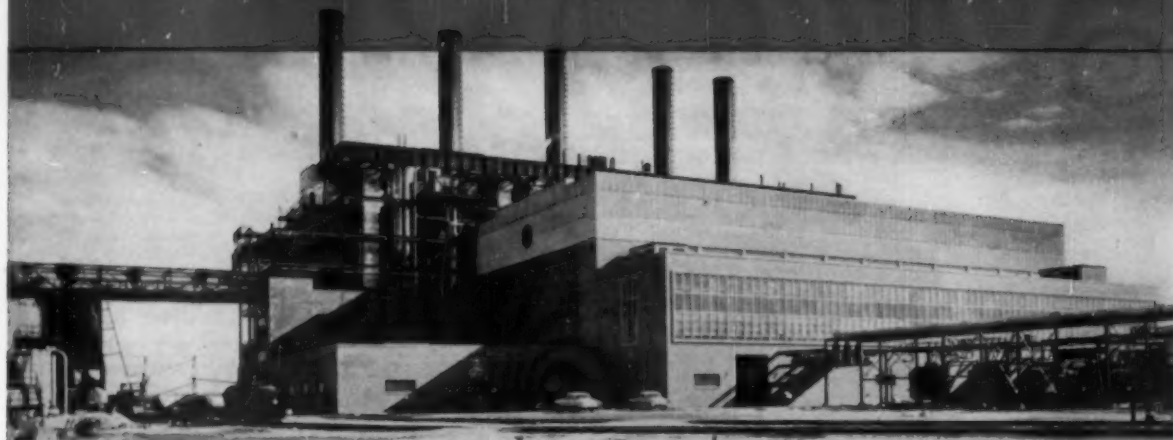
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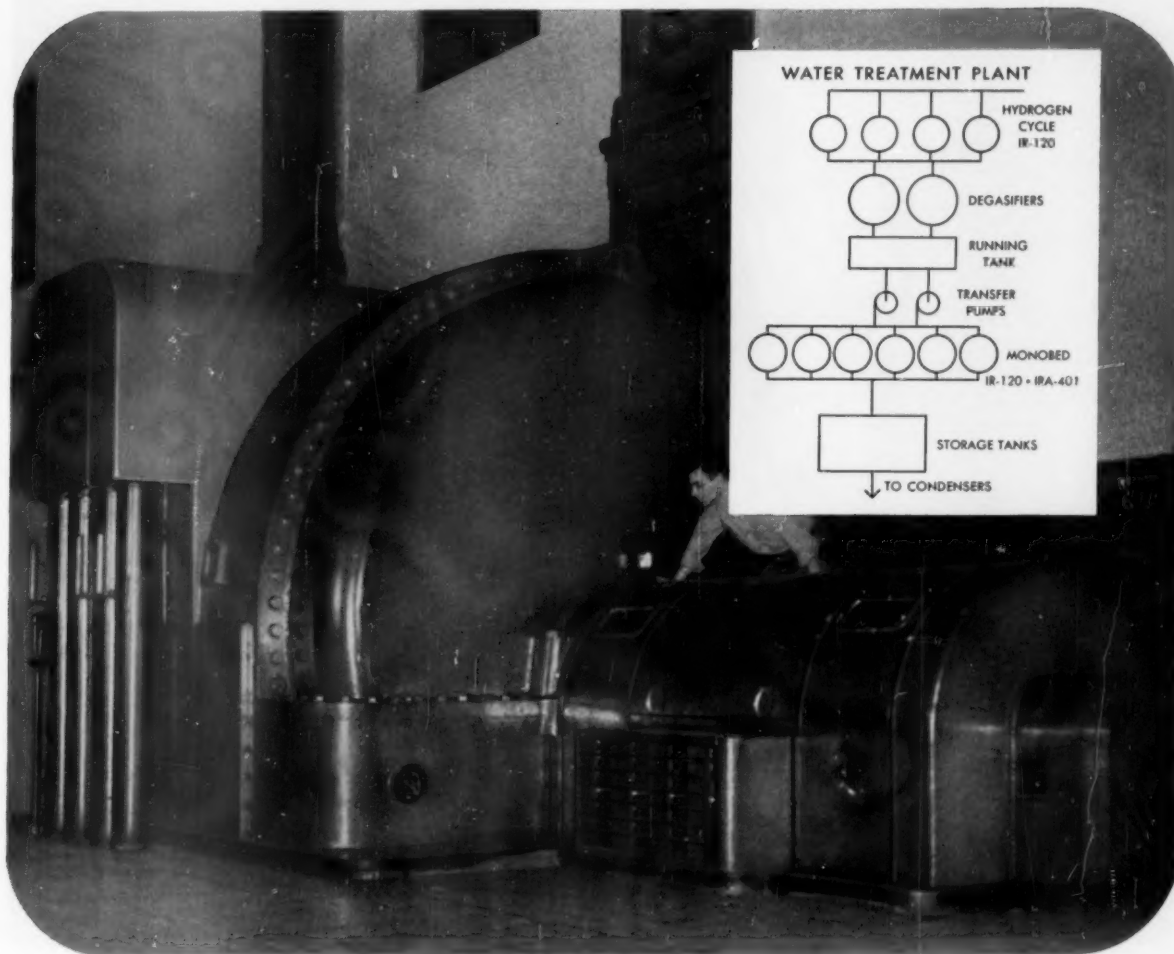
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This is the impressive record of the AMBERLITE ion exchange resin installed in 1954 at Consolidated Edison's Waterside station in New York. The water supply for this power generating station passes first through 4 beds of AMBERLITE IR-120 cation exchange resin operating in parallel in the hydrogen cycle, then through 6 MONOBED units in parallel (using one-third AMBERLITE IR-120 and two-thirds AMBERLITE IRA-401 anion exchanger) to provide a deionized water supply of extremely low mineral content. The MONOBED units have now gone through over 3,000 regeneration cycles.

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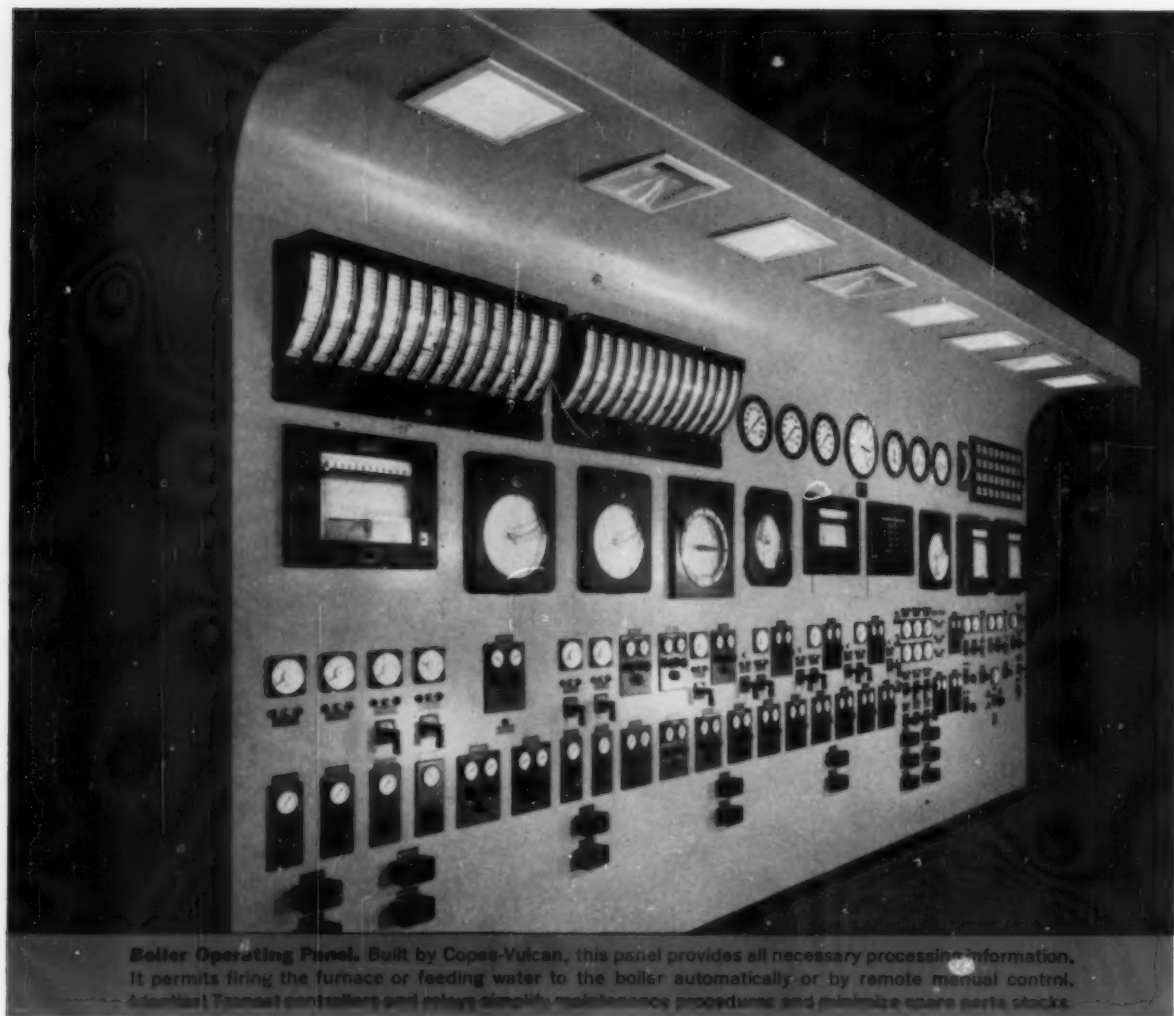


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**Boiler Operating Panel.** Built by Copes-Vulcan, this panel provides all necessary processing information. It permits firing the furnace or feeding water to the boiler automatically or by remote manual control. 4-point (Tennant) controllers and relays simplify maintenance procedures and minimize spare parts stocks.

## Copes-Vulcan Boiler Control installed at Seward Station

Pennsylvania Electric Company's Seward Station uses an integrated Copes-Vulcan system to provide efficient boiler control. Built to maintain a constant main steam-header pressure under all load conditions, this modern control system provides simplicity of circuits and dependable accuracy of components.

**Correcting pressure changes automatically.** Fuel feed responds to deviations in steam pressure resulting from changes in steam flow rate, and generates the exact amount of steam to restore header pressure. The system also maintains constant drum level.

Mill temperature control, mill-totalizing circuit and boiler feed pump recirculation control are addi-

tional functions of this efficient control system.

**Bumpless transfer simplifies operation.** All Copes-Vulcan auto-manual stations provide a continuous picture of performance, permit automatic-to-manual selection without the complications of seal balance.

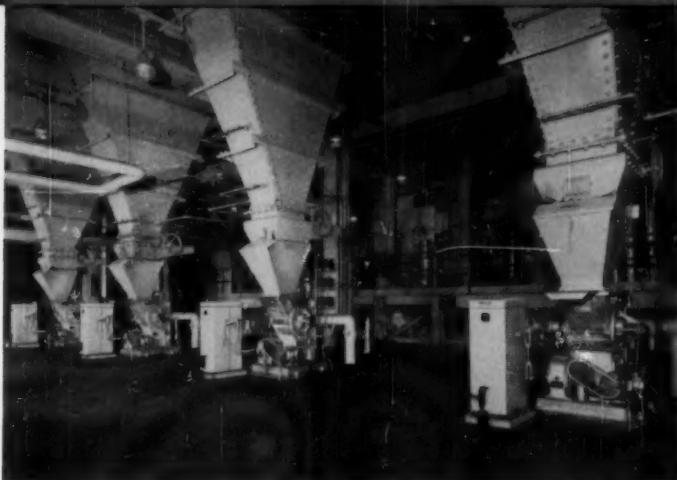
Noted for modern design, high speed response and precision performance, Copes-Vulcan boiler control systems and Vulcan soot blowing systems cut operating costs at modern stations everywhere.

Whether your boiler is large or small, power or process, your Copes-Vulcan representative has the ideas, information and experience to help you choose the system to best meet your needs.

# C-V NEWS NOTES

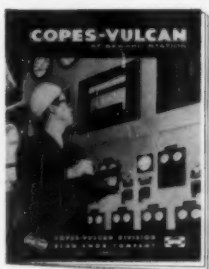


**Seward's soot blower system.** A Vulcan automatic-sequential control system keeps soot blowers operating in proper sequence. Panel switches permit any soot blower to be cut out of the sequence or rebrown if necessary.

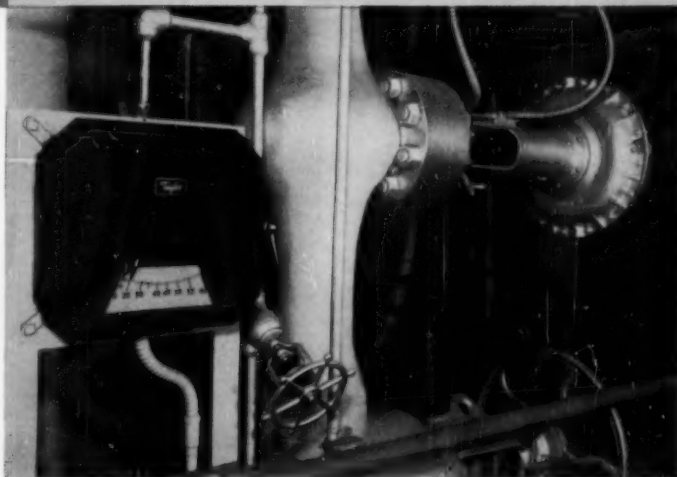


**Fuel feed drive units.** The units shown are typical of all drive units in the control system. A positioner, a four way valve, a power piston and feed-back cam are incorporated into each compact unit.

**Pump recirculation control.** When discharge from any pump falls below an established limit, an electric-contact low-flow control circuit opens a diaphragm operated by-pass valve to assure sufficient flow to prevent the pump from overheating.



**Write for Bulletin 1038.** This 12-page bulletin describes in detail Seward's complete control system. Schematic drawings show air-flow and fuel-loading loops. Boiler drawings locate Vulcan soot blowers and wall deslaggers.



**COPES-VULCAN DIVISION**  
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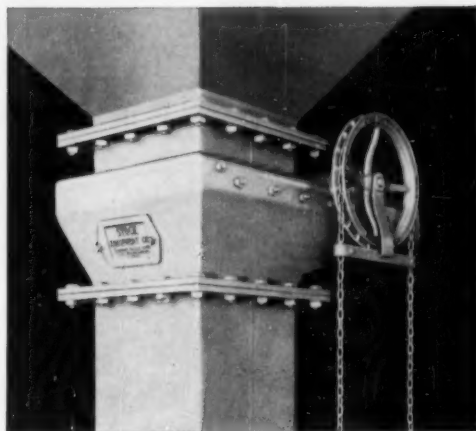
## Dramatic "upside down" test tells

# The inside story on the S-E-CO Coal Valve...

The simple test illustrated here proves graphically that the S-E-CO Coal Valve works under almost any kind of condition—even while it's standing on its head.

One reason for the superiority of the S-E-CO Valve is the exclusive self-cleaning design of the racks and pinions. Double pinions on either side of the gate project *through* the ladder racks, because the root portions of the racks have been eliminated. There is no place for coal to build up and cause jamming or cocking. This self-cleaning design helps the S-E-CO Valve operate smoothly and easily, even after long periods of infrequent use.

There are many other features that help to make the S-E-CO Coal Valve your best valve buy. Just one word of caution. Be sure to install *your* S-E-CO Valve right side up. It works even better that way.



**BUILDING THE STANDING COLUMN**

Valve is inverted and filled with coal. In this position racks and pinions are exposed. Normally an extra deep U-shaped gate protects them from contamination by coal particles.



**PACKING THE COAL AGAINST PINIONS**

2 x 4 is used to spread coal through valve and pack it against pinions (see opposite page). Don't forget, the valve gate must force its way through the coal that already fills the valve.



**EVEN UPSIDE DOWN... IT CLOSES!**

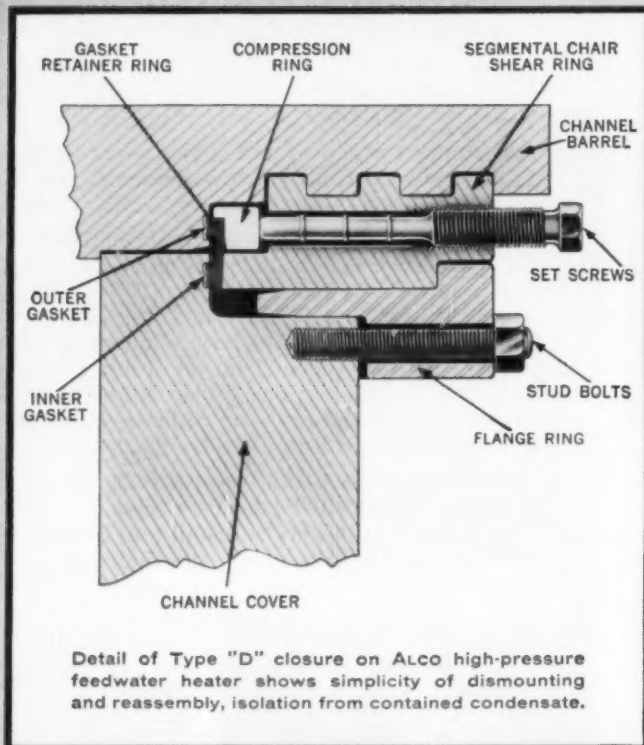
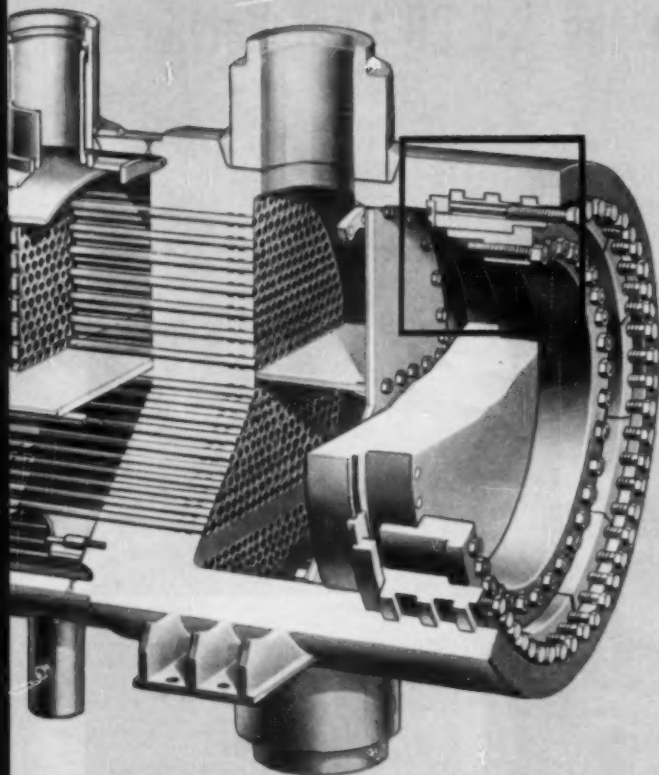
Here's proof that S-E-CO racks and pinions are *truly* self-cleaning. Valve gate closes, completely. And it opens again, all the way. If it works under these conditions, it will work even better for you.

*Get the rest of the inside story on the S-E-CO Coal Valve. Send now for Bulletin 97.*

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Specialists in any ALCO sales office will be happy to discuss with you in detail the design, construction and many advantages of the ALCO Type "D" closure on feedwater heaters. For an informative brochure, write ALCO Products, Inc., Dept. 135, Schenectady 5, New York.

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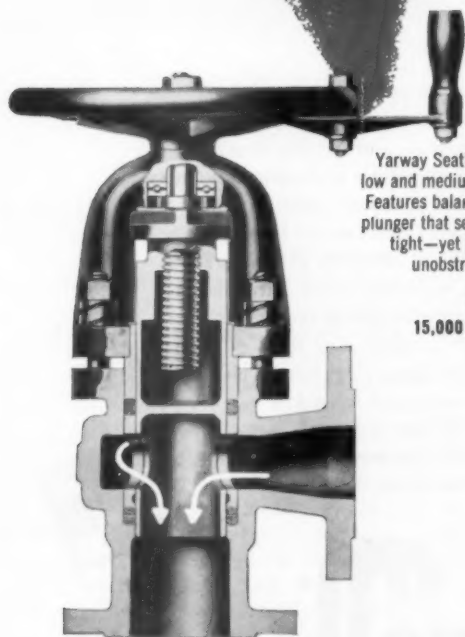
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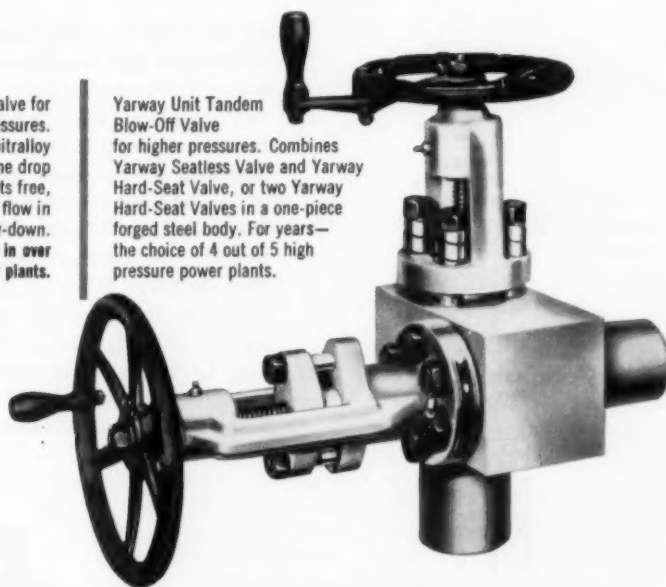
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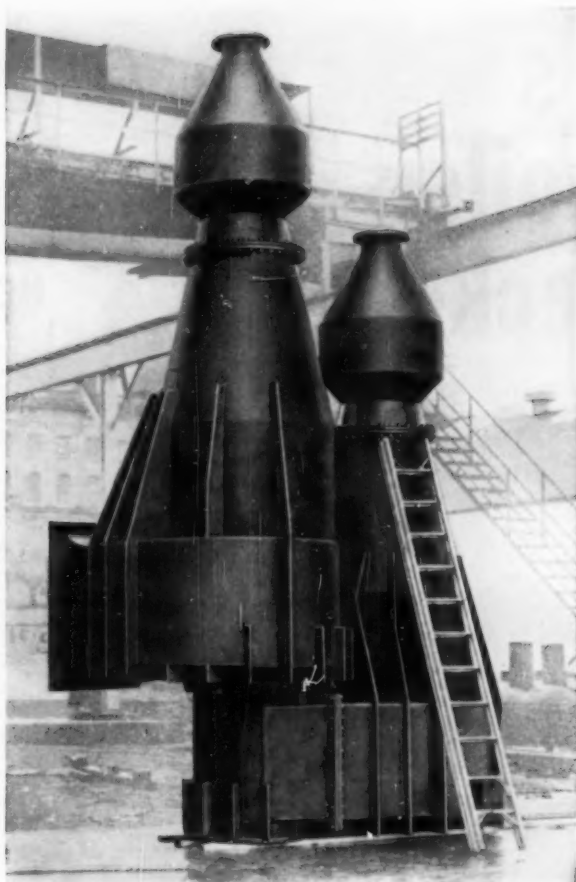


Yarway Unit Tandem Blow-Off Valve for higher pressures. Combines Yarway Seatless Valve and Yarway Hard-Seat Valve, or two Yarway Hard-Seat Valves in a one-piece forged steel body. For years—the choice of 4 out of 5 high pressure power plants.

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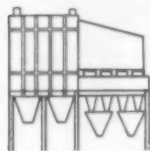
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# COMBUSTION

## Editorial

### Craftsmanship Lives On!

Engineering legend passed down over the centuries has it that James Watt successfully developed the steam engine after many others had failed largely because he found skilled craftsmen who could bore a cylinder diameter to within plus or minus  $\frac{1}{8}$  inch. Much has changed since James Watt first achieved fame as a mechanical engineer, but one thing is unchanged—and is likely to remain so: the ability of highly skilled workmen to translate the blueprint designs of the engineer to the solid reality of formed metal.

No less a world leader in atomic energy than Walker Cisler, president of Detroit Edison Company, Atomic Power Development Associates and Power Reactor Development Company, had this to say about the men of Combustion Engineering's Chattanooga Division who have just completed manufacture of the most complex stainless steel reactor vessel ever built:

"This component . . . marks the completion of a special kind of task that has never been done before. And it is

most important that successful completion of this vessel could not have been achieved without the skilled shop craftsmen whose know-how enabled them to perform the many unique and specialized hand operations required."

Mr. Cisler made these remarks on April 22 to a group of executives of member companies and suppliers of Atomic Power Development Associates. The occasion was the transfer at the Miami Fort Station of The Cincinnati Gas and Electric Company of the reactor vessel for the Enrico Fermi Atomic Power Plant. After being lifted from an Ohio River barge to a flat car, the 91-ton APDA vessel continued its intricate, close-clearance railroad movement to the plant near Monroe, Mich., where it arrived on May 1.

One observation seems appropriate to the successful construction and transportation of this unusual stainless steel pressure vessel. It is this. Physicists may hypothesize, designers calculate and engineers dream, but in the final analysis only craftsmen build.

### It Has to Come

The modern power plant involves a high capital expenditure and every possible precaution must be taken to keep the equipment that expenditure represents "on the line" to realize a sensible return on this investment. Further, as the average power plant unit has grown in size its auxiliaries, its operating controls, its monitoring devices have had to meet more exacting demands to attain this "on the line" condition. The question naturally arises as to where does it all end.

At the recently concluded First Annual Power Conference of the Instrument Society of America, W. A. Summers, Ebasco Services, pointedly identified one problem of the immediate future. We quote: "As plant investment cost and hazard cost increase, and assuming no improvement in control, an operator's speed of response and correctness of decision must increase proportionately. This we cannot expect for we are already encountering human limitations during system upsets." The solution as Mr. Summers sees it is plant automation. Says he, "It has to come."

The usual support for the adoption of automation is the expected savings it will achieve for a finished product.

Since these savings are based on projections of factors whose significance can be appreciated only by those directly involved in manufacturing industries the arguments for automation have always seemed to us academic. Not so with Mr. Summers' analysis.

The penalty, according to Mr. Summers, for a single error in judgment or procedure between now and 1975 will become financially prohibitive. For example, a limited accident which might cost \$50,000 in 1956 would cost \$180,000 by 1975. A serious accident (about three-quarters of a million dollars in 1956) would cost about two and one-half million in 1975.

Moreover, human engineering studies have found man, the traditional arbiter of judgment and procedure, to be slow, inconsistent, easily bored by repetitious tasks and affected by human environment. Theoretically, automatic control should out-perform human control in operation of a power plant. The power plant man of the future, hence, will be employed for his superior skills of analysis, planning, detection and repairing. We find ourselves convinced along with Mr. Summers that automation has to come.

At high steam pressures and temperatures, reheat levels and unit outputs, the control of a steam boiler becomes a matter of the greatest importance. Generally speaking, good results are obtained only when the working principle of the boiler and the control system are attuned to each other. The control system of the Sulzer Monotube steam generator was designed at the same time as the boiler itself and has since been continuously adapted to advances in boiler engineering.

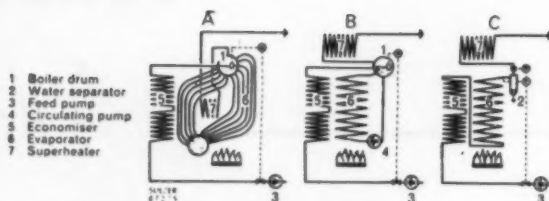


Fig. 1—Working diagrams of natural-circulation and forced-circulation boilers. A natural circulation, B forced circulation, C Sulzer Monotube

## The Control of the Sulzer Monotube Boiler\*

BY J. PROFOS

Sulzer Brothers, Ltd.

FOR many years steam boiler control systems were regarded as accessories of secondary importance. Everything connected with them was thought of as being the business of the supplier, with which the boiler builder need not occupy his mind. Today it is being increasingly recognized that the designers of boilers and control systems must cooperate closely if a maximum of reliability and economy—the final products of efficient control—are to be attained.

In the Sulzer Monotube steam generator this close cooperation was accepted as a principle from the first. When the company began their work on this type of boiler, they developed a control system for it at the same time. The obvious course was to base the design of the control system on that of the steam turbine, and this is in fact what was done. The implication was that the system would have to satisfy the same high requirements as that of the turbine to which steam was to be supplied.

Over twenty-five years have elapsed since the first Sulzer Monotube steam generator went into industrial service. Steam temperatures and unit outputs have risen considerably since then, single and even double reheat has been adopted, and finally the critical pressure limit has been passed.

The control system has had to keep pace with these growing requirements and has been brought into its present form as a result of close contact between clients, commissioning engineers and theoretical workers. In spite of the many improvements made, the basic features of the original design have been retained and have been carried over even into the domain of supercritical pressures. At present the makers have the results obtained in over a hundred plants at their disposal, as well as a good deal of up-to-date data on questions of theory and design.

Sulzer Brothers were probably the first firm of boiler builders to make a thorough theoretical and experimental study of transfer characteristics in the various controlled systems of once-through forced-circulation boilers. The frequency response methods which are now being widely adopted were successfully applied to difficult problems

(such as that of temperature control in superheaters) more than ten years ago. This furnished valuable data for the optimum design and application of controllers while making it possible to form a reliable picture of the behavior of controlled plants even when they were still in the project stage.

### Principle of the Sulzer Monotube Steam Generator

The operation of the boiler and its control system are so closely bound up with each other that a short description of the principle of the Monotube steam generator must preface the following remarks.

The Monotube steam generator is a typical embodiment of the once-through forced-circulation design. The water delivered by the feed pump flows in succession through the heating surfaces constituted by the parallel tubes of economizer, evaporator and superheater. At the end of the evaporating zone, at a point where the mixture of steam and water still contains a small percentage of moisture, a water separator is fitted, so that the steam passing to the superheater is practically dry. This separator serves to remove the salt from the working medium and plays a part in control as well as performing safety functions: it keeps the condition of the steam at the superheater inlet constant.

The working principle of the Monotube boiler can best be explained by comparing it with that of natural-circulation and forced-circulation types. Whereas in natural-circulation boilers (diagram A, Fig. 1) the circulation in the evaporator results from the upward movement of the steam bubbles, it is produced in forced-circulation boilers (diagram B) by a special circulating pump 4. Diagram C shows that in the Monotube steam generator this circulation in the evaporator has been replaced by a simple once-through flow.

It is obvious that big steam generators cannot consist of a single tube, but that the economizer and evaporator on the one hand and the superheater surface on the other must be made up of parallel tubes (each handling from 20,000 to 33,000 lb per hr). A characteristic feature for the once-through design is that the evaporator forms a single unit with the last part, at least, of the economizer, no intermediate headers being used. This system is

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chosen to ensure stability of the water distribution and gives the Monotube steam generator its favorable properties in this respect. Fig. 2 is a drawing of a boiler for supercritical pressure with double reheat.

The control of a boiler is essentially a complex problem. A plurality of factors, some of them interdependent, must be kept under control, and there are numerous possible sources of disturbance. Although the nature of the control system is closely bound up with the working principle of the boiler, there are usually several alternatives, and a good deal can be gained by skillful handling of the problem. In this respect the evolution of the control system as part and parcel of the Monotube steam generator was a point of the greatest importance. Instead of the finished boiler being placed before the control engineer, the whole design included the control methods from the first. It was therefore possible to set out from the following principles:

(a) Division of the whole complex control problem into clearly defined component parts which are easy to handle, as nearly independent of each other as possible and amenable to theoretical treatment. This simplifies the supervision of the control system in service and facilitates optimum adjustment. A typical example is the almost complete independence of the feed and temperature control systems.

(b) Creation of dynamically favorable controlled systems. This is a prerequisite of highly efficient control but demands very close collaboration between the boiler designer and the control engineer. A typical example is the arrangement and subdivision of the superheater for the purposes of temperature control.

#### Functions of the Control System

We shall consider first of all a simple case of a plant for moderate live-steam temperature without reheating. Fig. 3 is a diagram of a condensing plant with a Sulzer Monotube steam generator. The feedwater is taken from tank 26 and delivered into the boiler by feed pump 5 through valves 7/8 (feed control). It now flows through the economizer heating surface 1, through evaporator 2 and, after the residual moisture has been eliminated in separator 12, is brought up to the desired temperature in a first superheater 3 and final superheater 4. The steam now goes through valves 20/21 (pressure control) and passes in normal service to turbine 22. From condenser 23 the water is conveyed by condensate pump 24 through the extraction steam preheaters 25 (not shown in the drawing) and back into the feedwater reservoir 26. When the boiler plant is being started up or shut down, the working medium flows instead through bypass valve 21, which forms part of the boiler pressure control system, and direct into feedwater reservoir 26, thereby bypassing the turbine. The pressure-regulating overflow valve 28 ensures that the steam blows off to condenser 23 whenever condensation is impossible in reservoir 26. In this way at least the valuable condensate is recovered.

The diagram also illustrates the duties of the internal boiler control system. Thus the feed water control system (units 6, 7, 8, 9, 10 and 11) adapts the amount of water fed to the boiler to the heat supply in the combustion chamber in such a way that the condition of the steam at the inlet to the separator (relative humidity) always remains constant. It thereby keeps the end-of-evaporation point stationary in the heating surface.

The level control system in separator 12 (units 13 and 14) serves to drain off the water eliminated from the steam, maintaining the water level within narrow limits. Apart from its normal function, it also has a special duty at low loads: below a certain limit (usually 25–30 per cent maximum continuous load) it enables the feed quantity to be kept constant and the boiler to be operated indefinitely without the stability of the water distribution in the evaporator being jeopardized. The relative wetness of the steam approaching the separator then rises accordingly, so that it is justifiable to speak of circulation in the evaporator section. The water level control system also performs a special function in conjunction with the separator when there is a sudden reduction of the intensity of the fire, as it prevents the unintentional flooding of the superheater and the consequent danger to the turbine.

The temperature control system (units 15, 16, 17 and 18) serves to maintain a constant live-steam temperature. This end is achieved by injecting water between the first and second superheaters. (In many Monotube steam generators water is injected at several points.)

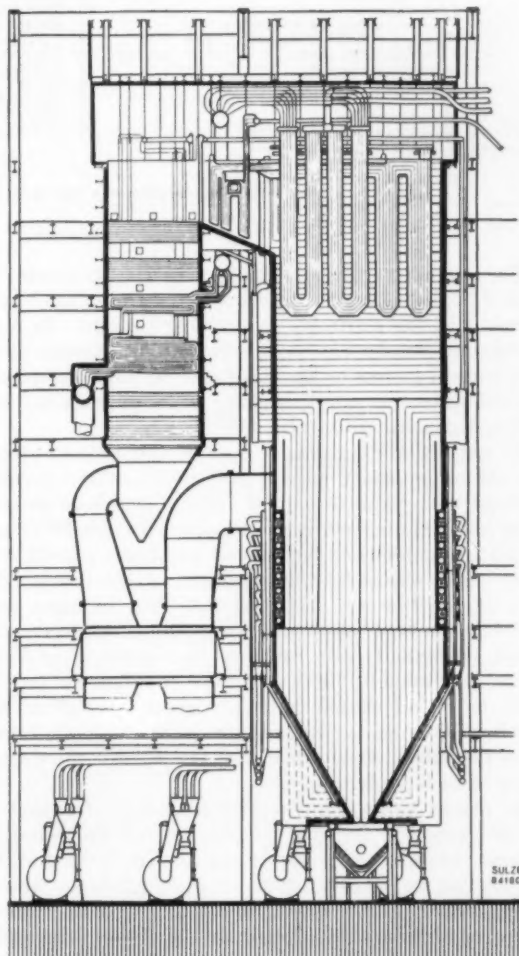


Fig. 2—Section through a Sulzer Monotube steam generator for supercritical pressure; 1,820,000 lb per hr, 5120 lb per sq in., 1200 F, with double reheat to 1050 F, (built under license by Combustion Engineering Inc., N.Y.)

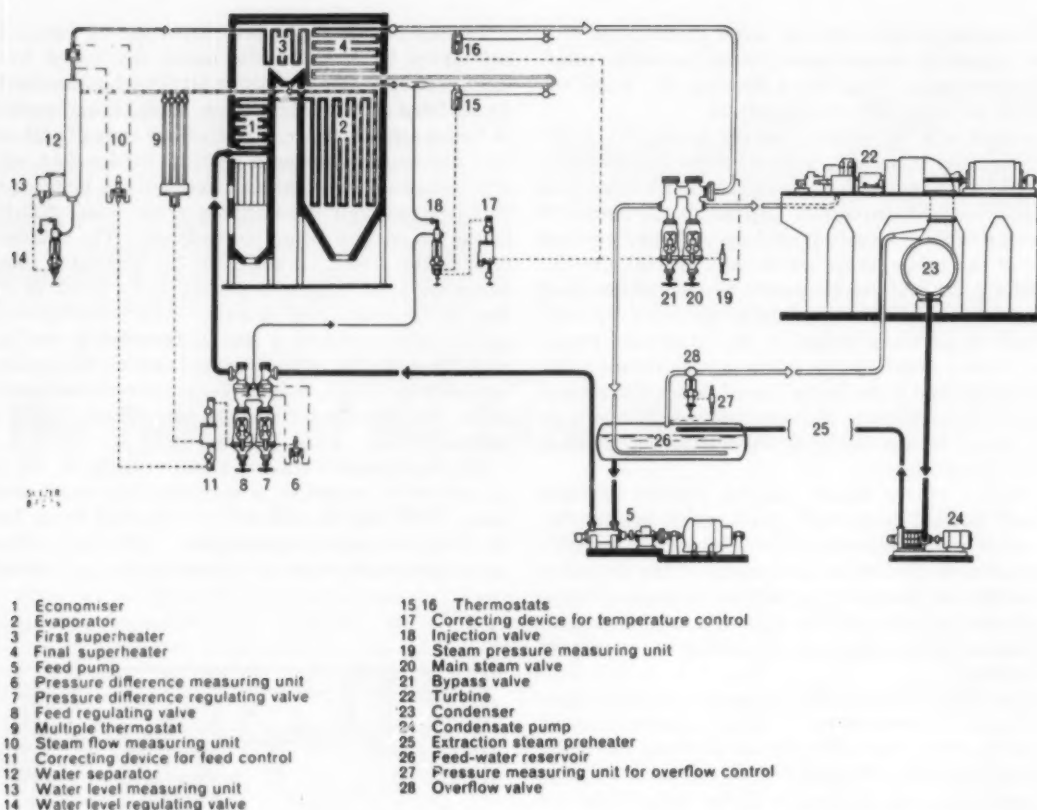


Fig. 3—Working diagram of a high-pressure plant with a Sulzer Monotube steam generator

The purpose of the pressure control system (units 19, 20 and 21) is to keep the pressure at the end of the boiler constant in the starting and stopping periods. In normal service this duty is taken over by the admission pressure control system of the turbine or by the combustion control system, in which case the boiler pressure control system has a safety function only.

At very high capacities it may be desirable to divide the steam generator system into two or three parallel sections with separate control. Fig. 4 is a diagram of a Monotube steam generator of this type for 440,000 lb per hr with a double tube system and two boiler control systems. The reason for this expedient is that it is impossible to distribute the heat uniformly over the many parallel tubes in very large units. Big differences may easily occur, particularly as a result of an asymmetrical flame in the combustion chamber. Thus the diagram on the right in Fig. 4 shows that the right-hand half of the combustion chamber has raised considerably more steam than the other, which illustrates graphically the desirability of such a subdivision.

In plants employing resuperheating, a control system is also required for the temperature of the reheated steam. Injection desuperheating is here limited in its application by considerations of cycle efficiency and is used primarily for rapid, temporary control action. Basic corrections are effected in the Sulzer Monotube steam generator either by surface coolers or by varying heating. The supply of heat can be regulated either with flue-gas dampers or—the alternative preferred in

America—with tilting burners. (See COMBUSTION Dec. 1956, p. 43).

This internal boiler control, which is common to all Sulzer Monotube steam generators, may be supplemented as conditions require by combustion control or regulating equipment for the rest of the plant.

#### Design of Equipment

The control of the Sulzer boiler is continuous and employs oil under pressure as a control medium. The system consists in essentials of measuring units, hydraulic servomotors with their control and regulating valves and special correcting devices for converting the signals, which impose the desired transfer characteristic on the control system.

In the measuring units any deviations of the controlled variable (pressure, temperature, etc.) are converted into proportional changes in an oil pressure. Thus the thermostat produces a difference of about 1 kg per sq cm in the oil pressure for a change in temperature of 40 deg C.

The oil pressure produced by the measuring unit is generally transmitted to the correcting device and is so transformed by this that the control action assumes the desired dynamic character, viz., integral or proportional-integral action. The same device may also be used for superimposing disturbances or for interconnecting two control loops. It again passes on the control signal in the form of an oil pressure.

This pressure acts on the control valve, which allows pressure oil to flow into the corresponding spaces of the

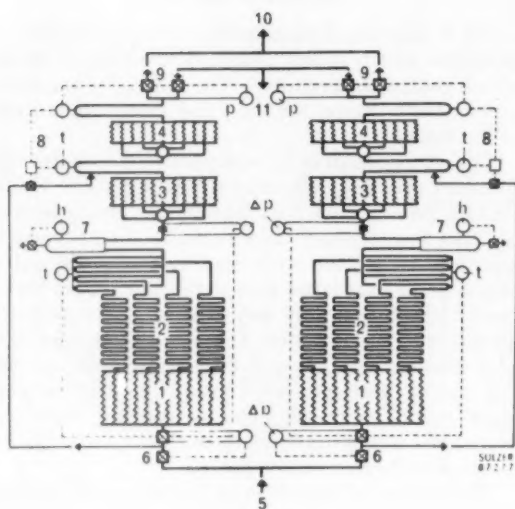
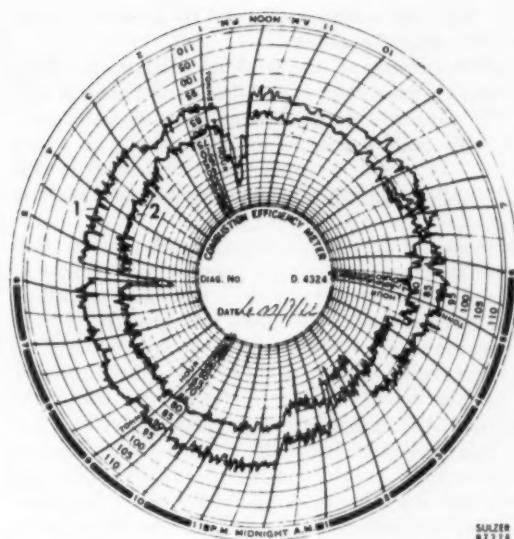


Fig. 4—Sulzer Monotube steam generator with two separately controlled steam raising systems. Left: diagram of the piping and control system



- |                          |                              |
|--------------------------|------------------------------|
| 1 Economiser             | 7 Water separator            |
| 2 Evaporator             | 8 Superheater control system |
| 3 Convection superheater | 9 Steam and bypass valves    |
| 4 Radiation superheater  | 10 Steam outlet              |
| 5 Feed-water inlet       | 11 Bypass outlet             |
| 6 Feed-water controller  |                              |

Right: diagram of steam production in the two halves of the boiler. Curve 1: right-hand half of boiler. Curve 2: left-hand half of boiler

servomotor, which in its turn operates the regulating valve. These hydraulic servomotors can be designed for almost any forces and for relatively high rates of adjustment; if necessary, they may also incorporate a reset mechanism. It is thus possible, particularly in simple control problems, to give the system a proportional, integral or proportional-integral character simply by the choice of the reset mechanism (i.e., without any special correcting device).

A few other features are inherent in the design of the Sulzer control equipment. Thus the short servomotor closing times, the very small time constants of the measuring units and the practical absence of time lag in the hydraulic transmission system are favorable from the point of view of control dynamics.

The high accuracy of the static signal transmission system is also characteristic. It is the result of a special pulsator which superimposes a small additional oscillation of about 60 cycles per min on the oil pressures produced by the measuring units. The whole control system from the measuring unit to the servomotor and the regulating valve consequently fluctuates slightly about the steady-state position, thereby eliminating the detrimental effects of friction. The inertia of the system is reduced in this way to negligible values, while the sticking of any part, particularly the regulating valves, is definitely precluded.

An outstanding feature is the simple and robust construction of all the parts, which measure up to the heavy duty of the boiler-house in every respect. This makes adjustment, supervision, servicing and overhauling much simpler.

The sturdy construction of the control equipment is clear from Fig. 5, which is a cross-section of a steam stop valve for a working pressure of 182 kg per sq cm (2590 lbs per sq in). Like all the regulating valves used in Sulzer

Monotube steam generators, it is of the single-seating type, the advantages of which need not be enlarged upon here. The very great adjusting forces required can of course be produced without difficulty by the oil-operated servomotors, even when short closing times are also de-

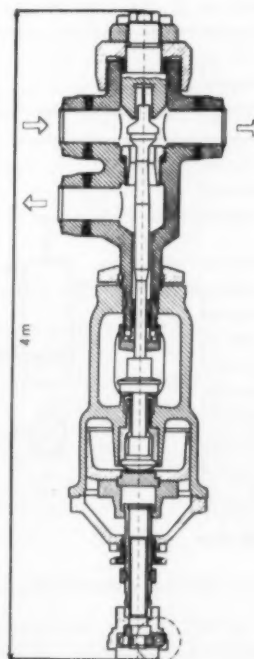


Fig. 5—Simplified section through a steam pressure control valve operated by oil under pressure

manded. The valve can be adjusted by hand or can be locked in any desired position.

The inflammability of the working medium is sometimes cited as a disadvantage of oil-operated control systems. The danger of fires, however, is small, as long experience with boilers and steam turbines of all types has shown. It is also possible today to reduce it still further by using a practically non-inflammable working medium.

Other means of transmission can in any case be used for certain functions. Thus the remote adjustment of settings and of servomotors or the check-back signalling of the positions of regulating valves is frequently effected by electrical means. Electric units can even be used for control functions proper where they offer real advantages. Under certain conditions, for instance, the controlled variable, e.g., the superheat temperature, may be electrically measured and transmitted, and the correcting devices also may be electrically operated. This does not mean that the advantages of the hydraulic servomotor, viz. high adjusting forces and speeds, have to be sacrificed; instead, the servomotor is actuated through a special transformer which converts the electric into hydraulic signals.

The use of electrical equipment facilitates the incorporation of supervision and control apparatus in thermal control stations. It permits carrying out all the important maneuvers by remote control from a central station.

## Method of Operation

Fig. 6 is a control diagram of a Sulzer Monotube steam generator which shows, generally speaking, only the internal control equipment. The external equipment required, for instance, for the firing system is not entered in the diagram.

The water drawn in by feed pump 5 passes through the so-called pressure difference regulating valve 7 and the feed regulating valve 8 to the boiler. There the working medium flows through the economizer 1 and evaporator 2 and thus reaches the water separator 12. The saturated steam leaving the latter goes to the first part of the superheater 3 and thence by way of an injection point to the second superheater section 4, where it is brought up to the final temperature. It now flows to the pressure regulating station and normally enters the turbine through main steam valve 20. During starting and stopping operations it flows instead through bypass valve 21 and direct into the feed reservoir.

The method of operation of the individual control systems will now be considered in more detail with the aid of this diagram.

## Feedwater Control

Feedwater control is effected in much the same way as in drum-type boilers. When a change of load occurs, the feedwater quantity is roughly adjusted by a steam flow

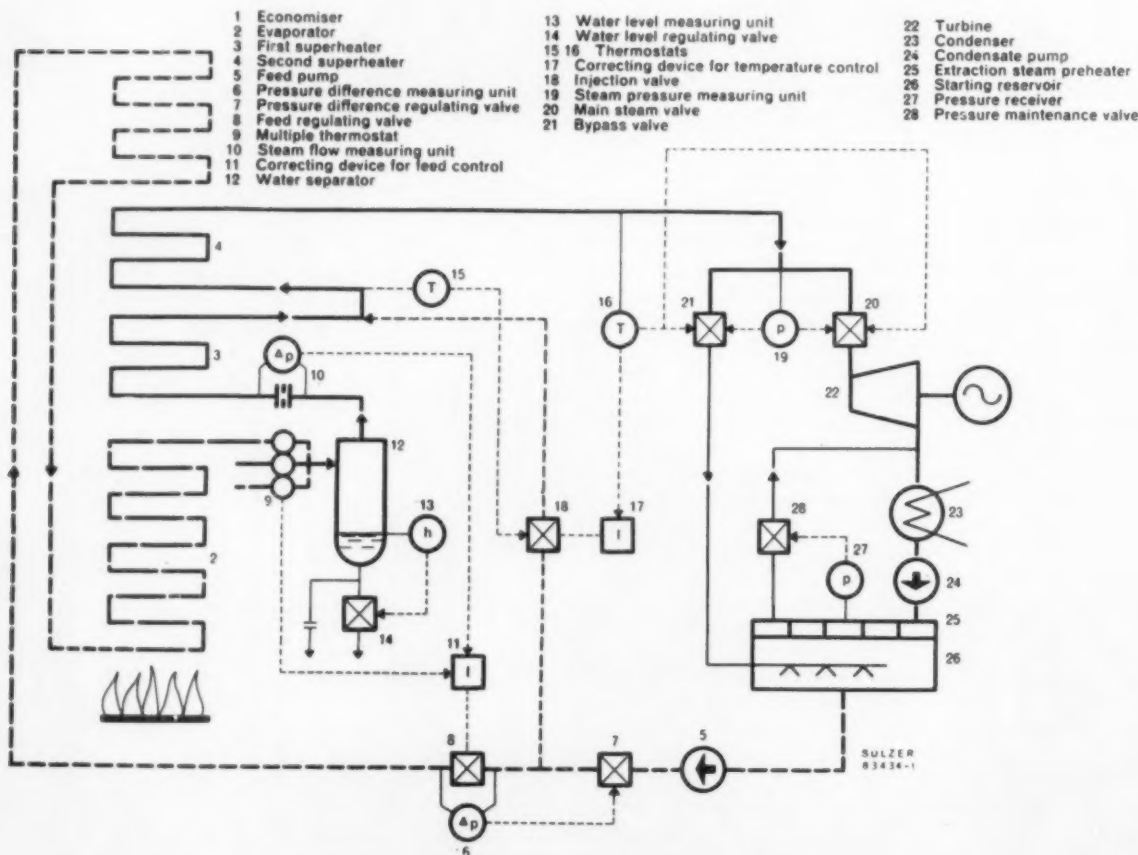


Fig. 6—Working diagram of the control system of the Sulzer Monotube steam generator

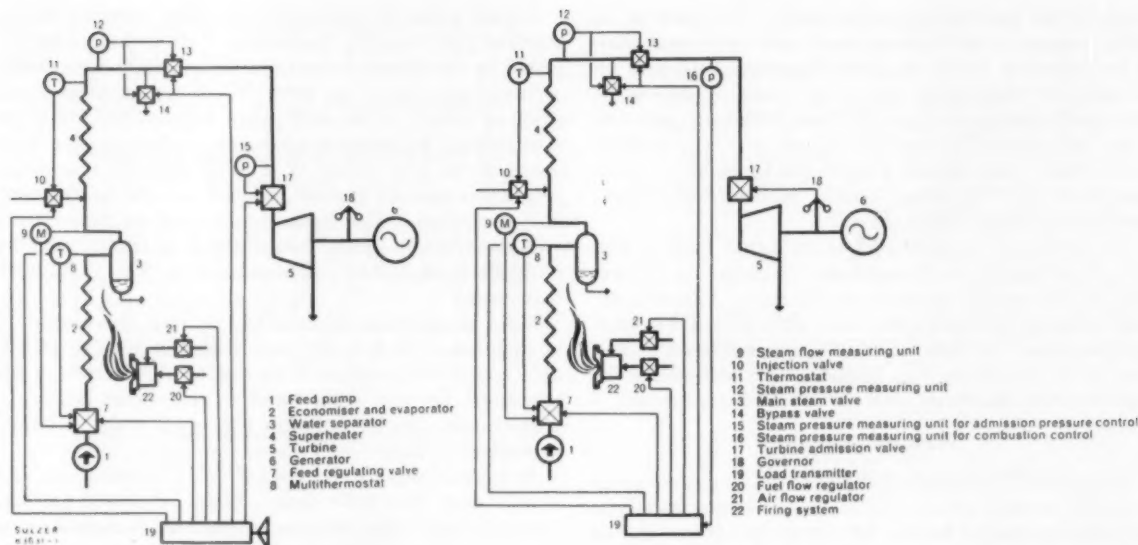


Fig. 7—Control systems for Sulzer Monotube steam generator plants

Left: Control diagram for service with admission pressure control

Right: Control diagram for service with combustion control

signal which acts in the same way as a superimposed disturbance. This auxiliary signal comes from pressure difference measuring unit 10, which is located immediately downstream from the separator. The fine regulation, which in the drum-type boiler is a function of the water level, here depends on the temperature of the working medium approaching the separator, as measured by thermostat 9. The two control signals are first transmitted to the correcting device 11, where they are transformed and superimposed. The resulting signal acts on the servomotor of feed regulating valve 8. The control action is essentially proportional-integral.

The temperature of the steam at the evaporator outlet, where it is still slightly wet, is of course no measure of its thermodynamic state at the inlet of the separator. It is therefore arranged for one of the parallel evaporator tubes (represented by the middle tube in Fig. 6) to receive rather less feedwater, so that the steam leaving it is slightly superheated. Its temperature is then a reliable criterion of the condition of the steam and thus of the ratio of combustion intensity to feedwater flow. The danger of salt deposits forming in a tube which is continuously superheated is slight, as experience has shown, this being due to the effective removal of salt in the separator. So far no damage to tubing has ever resulted from this cause. The tube in question can also be flushed out at intervals by manual or automatic adjustment; nor is it necessary to superheat the same tube all the time. This is one of the reasons why several (and quite often all) evaporator tubes are fitted with thermostats at the outlet (Fig. 6). The result is the so-called multithermostat device. In the example illustrated four of eight parallel tubes are fitted with a contact thermostat. These are mechanically connected in such a way that only the signal from the transmitter on the tube at highest temperature is passed on to the control system.

In principle the measuring element here is the whole tube coil running from the economizer inlet to the evaporator outlet, and thus a part of the normal heating surface. It is consequently exposed to the same influences

as the whole controlled system, is equally heated, undergoes the same amount of slag formation and—most important of all—has the same dynamic transfer properties. In other words, it reproduces perfectly the behavior of the controlled system.

The pressure difference regulating valve 7 (Fig. 6) also belongs to the feedwater control system, as it serves to keep the pressure difference at valve 8 constant. The fact that the characteristics of the boiler and the centrifugal feed pump run in opposite senses is unfavorable for control purposes and is therefore counteracted by this arrangement, which ensures that the feedwater flow depends on the opening of the feedwater regulating valve. Measuring unit 6 measures the pressure difference and converts it into an oil pressure which acts directly on the control valve of the servomotor for valve 7, which has no reset mechanism. In large steam generators this valve is often omitted, the pressure difference being kept constant by regulating the speed of the feed pump. In most cases, however, both expedients are combined, as the standby pump is frequently not designed for speed adjustment.

#### Water-Level Control in the Separator

This control system is particularly simple. Level transmitter 13 (Fig. 6) measures the water level in separator 12, and the corresponding oil pressure is transmitted to the control valve of servomotor 14 controlling the discharge valve. This servomotor is fitted with a reset mechanism which makes the control action proportional. It may be mentioned that the blowdown, by which salt is removed from the circuit, is independent of this water-level control system.

#### Temperature Control

As already mentioned, the live-steam temperature at least is regulated by injection. The injection quantity is determined by thermostats 15 and 16, fitted immediately downstream from the point of injection and at the

outlet of the superheater respectively. Thermostat 15 passes a signal direct to the control valve of the servomotor for injection valve 18, while thermostat 16 acts on the same servomotor by way of a correcting device 17. The superheater control system thus consists in essentials of two interacting control loops, one of them being a quick-acting proportional control for immediate coarse corrections and the other a slow proportional-integral control for precision adjustment.

The quality of superheater temperature control also depends, of course, on the constancy of the steam temperature at the inlet to the first superheater. This temperature remains constant even when that at multithermostat 9 varies. As only one tube is superheated at any time, while the others, e.g., 10 still supply wet steam, the steam leaving the separator is almost always saturated.

### Pressure Control

The Sulzer Monotube steam generator is equipped with a special pressure control system which is not usually in operation in normal service but comes into action during starting and stopping operations and whenever disturbances occur. It comprises main steam valve 20 in the steam pipe to the turbine and bypass valve 21 which allows the steam to flow to the starting reservoir. Both are under the influence of the common pressure measuring unit 19, as the oil pressure produced by this acts simultaneously on the control valves of their servomotors. The latter have no reset mechanisms, so that the control action is integral. The important point is that the fixed steady-state value to which every integral controller tends to return is different for the two valves, the bypass valve being set to a somewhat higher desired value. The result of this is that, when the steam pressure lies between the two set points, the bypass valve is completely closed and the main steam valve completely open. The breadth of the pressure range thus produced can be adapted to requirements. When admission pressure control is employed at the turbine, it is usually fairly small (about 3 to 5 per cent of the boiler pressure); with combustion control it may be 10 per cent or more.

Bypass valve 21 maintains the boiler pressure during starting and stopping operations. Its orifice is so adjusted by the pressure controller that exactly the amount of steam generated can flow off. When troubles occur (such as failure of the feed pump without the fire being extinguished at once), it serves as a safety device, as it opens under the action of a limit signal. The boiler pressure is thereby rapidly reduced and the heating surface protected. The limit signal may be taken from various sources: quite frequently it is transmitted by multithermostat 9 or, as indicated in Fig. 6 by final thermostat 16.

Main steam valve 20 is locked by final thermostat 16 in such a way that it only opens when a definite adjustable steam temperature is exceeded, irrespective of the pressure. On the other hand it also closes when the temperature rises inadmissibly high, so that the turbine is protected.

In normal service the bypass valve is closed and the main steam valve fully open. When admission pressure control is used, the final boiler pressure is regulated by the turbine control system, otherwise by the combustion control system.

### Admission Pressure or Combustion Control

With admission pressure control as used in many Sulzer plants the desired value is chosen so that it lies between the response levels of the main steam valve and the bypass valve. This ensures that the two valves are in the position required for normal operation as mentioned above. The intensity of combustion is then first adjusted either directly or by remote control. In simple plants, as diagram 1 in Fig. 7 shows, only the air and fuel quantities are changed by a load transmitter 19, while the adjustment of the feedwater and injection quantities is left entirely to the internal boiler control system. In special cases, however, the load transmitter 19 may also emit signals for the preliminary adjustment (introduction of disturbances) or the alteration of the set point of the internal boiler controllers. Thus the set point of multithermostat 8 (Fig. 7) may be altered in order to com-

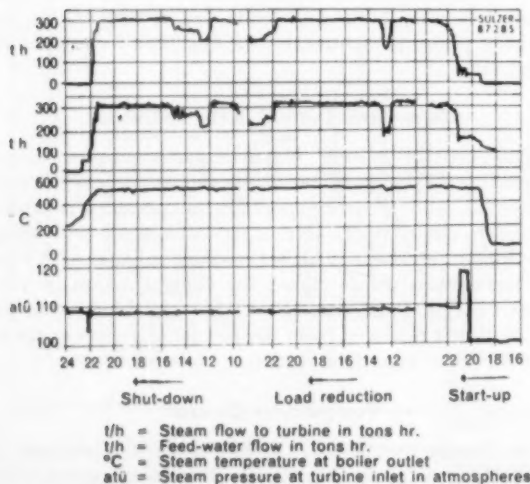


Fig. 8—Extracts from the service chart of a Sulzer Monotube steam generator for 660,000 lb per hr. On the right, start-up from cold

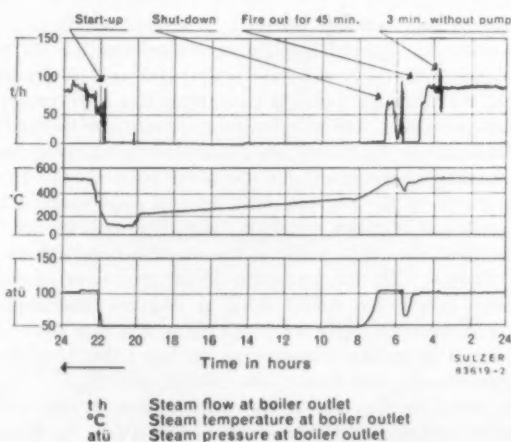


Fig. 9—Extracts from the service chart of a Sulzer Monotube steam generator for 275,000 lb per hr. Start-up with boiler still warm after interruption

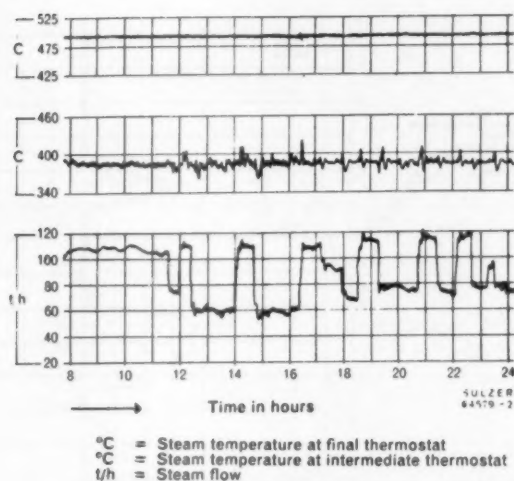


Fig. 10—Intermediate and final temperatures in a 275,000-lb Sulzer Monotube steam generator during severe load swings

pensate the displacement—as a result of load changes—of the saturated-steam temperature at the end of the evaporator and thus to ensure constant wetness of the steam at the separator inlet. Where stepped or sliding pressures are used, the response levels of the main steam valve 13 and bypass valve 14 can be adapted to the prevailing load, and so forth.

Diagram 2 (Fig. 7) illustrates *combustion control*: the final boiler pressure is controlled by altering the intensity of combustion. The turbine admission valve 17 is here influenced by the governor 18 and therefore depends on the load of the turbine set. Steam generation must be adapted to any change in the requirements by adjusting the intensity of combustion, the initial difference between supply and demand being bridged over by the storage capacity of the boiler. The diagram shows as an example how combustion is regulated in accordance with the pressure at the turbine inlet. As in the case of admission pressure control described above, the signal can act only on the air and fuel quantities. It is again possible, however, to emit further signals from the load transmitter to the internal boiler control system, for instance to the feed, temperature or pressure controllers or to several of these simultaneously. The pressure at the turbine inlet and thus at the boiler outlet once more moves between the response levels of the main steam valve and the bypass valve. Neither of these comes into action in normal service, and only in special cases—e.g., when the turbine is suddenly switched on to no-load—does the bypass valve open for a short time and thus prevent the safety valves from blowing off.

The final boiler pressure can of course be controlled in other ways than those mentioned above. Both admission pressure and combustion control can also be modified in their arrangement, and combinations of the two may sometimes be justified. These alternatives, however, lie outside the scope of this article.

#### Behavior of Control Systems in Practical Service

The quality of a control system, and particularly a boiler control system, naturally depends in the last definition on its reliability in practical service. Apart from a

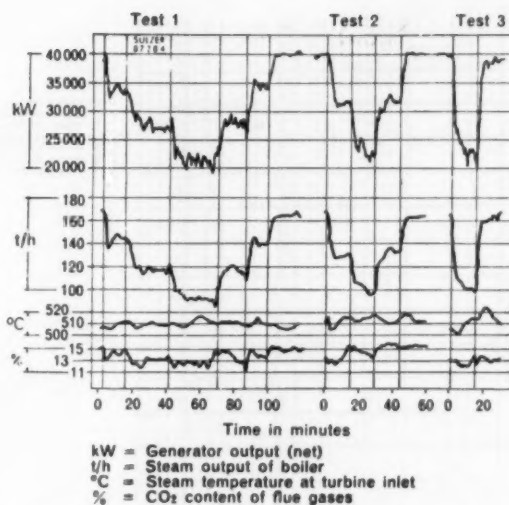


Fig. 11—Behavior during rapid changes of load with admission pressure control, recorded in a Monotube steam generator burning pulverised coal

few losses due to *force majeure*, all the controllers initially fitted in Sulzer Monotube steam generating plants are still in service today, in some cases after more than twenty years of operation. Many of the units have seen very heavy service and have had a minimum of attention. In one plant, for instance, the control system was found in a state of complete neglect just after the end of the war, covered by a thick layer of coal dust and dirt, but still in perfect running order. This control system is still in service today.

Working results are of course of primordial importance also. The control system of the Sulzer Monotube steam generator makes starting and stopping simple and safe. Fig. 8 is part of a service chart for a Monotube unit raising 660,000 lb-per hr. It illustrates a start-up from cold. It should be noted that the boiler burns wet coal, which involves fairly long starting periods. The curves show how the steam outlet temperature rises steadily from the moment when the pulverized coal firing system commences operation and comes up to the desired value without overshooting. The pressure attains the level set by the bypass control system shortly after the normal temperature has been reached and drops to the service level when the turbine set is put under load (i.e., when the admission pressure control system comes into action).

When the boiler is shut down, the steam flow is reduced fairly quickly as a result of the decrease in the heat supply, and the feedwater quantity is automatically cut down at approximately the same rate by the feed control system. The fire is extinguished at about 22.00 hr. The feedwater quantity remains at its minimum for a short time before the feed pump stops. In this way the temperature of the steam, which now flows through the bypass valve into the starting reservoir, is lowered slowly and steadily.

The curves reproduced in Fig. 9 show that starting is possible even after short interruptions of service. In this case a boiler of 220,000 lbs per hr burning pulverized lignite was started up again after having been shut down for three quarters of an hour. The steam temperature curve, which is here of primary interest, shows that absolutely satisfactory starting is quite possible without

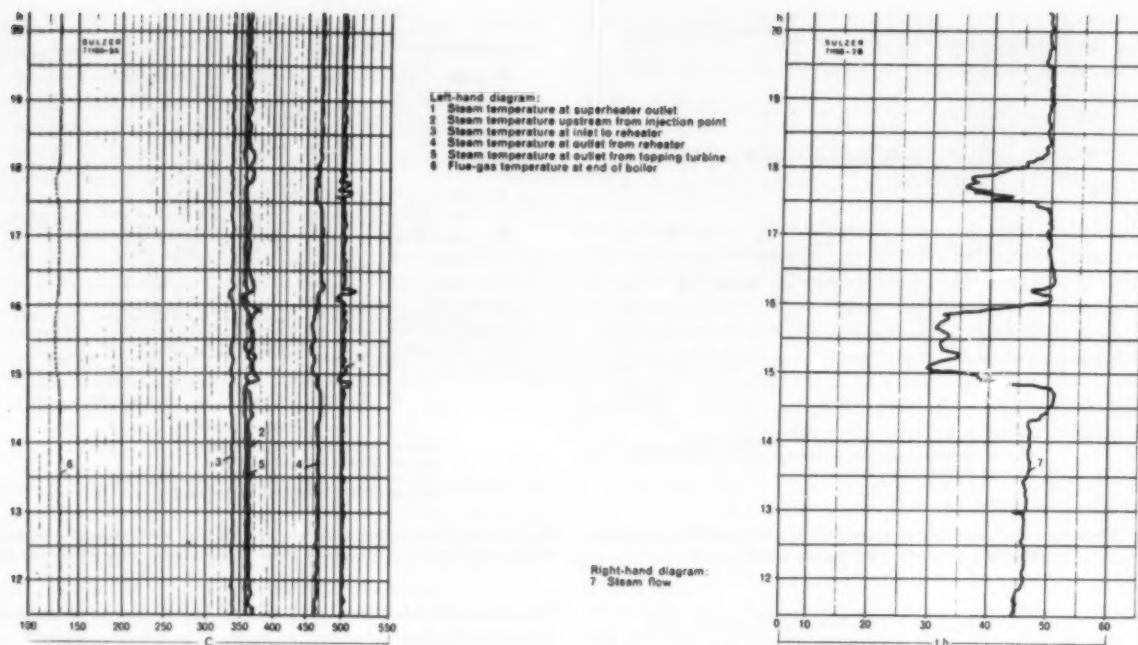


Fig. 12—Behavior during rapid changes of load with admission pressure control, recorded in a Sulzer Monotube steam generator with grate-type firing system and reheating, raising 120,000 lb per hr

any unusual rise in temperature under difficult conditions.

Special interest of course attaches also to the behavior of the boiler when sudden and pronounced changes of load occur. A distinction must here be made between plants with admission pressure control and those in which the steam pressure is maintained by combustion control. In the former case the storage capacity of the boiler is of secondary importance, as the pressure control system ensures that the turbine always takes as much steam as the boiler produces. Nevertheless, the behavior of the intergal boiler control system during rapid changes in the intensity of combustion is still important, and particularly the behavior of the temperature control system. Fig. 10 shows diagrams taken on the Sulzer Monotube steam generator for 275,000 lbs per hr which was formerly installed in a large power station at Mannheim. (The same boiler has now been converted to oil firing and is in service in France.) The steam curve shows a number of sudden and substantial load swings. The effect on the temperature of the feed control thermostat and of the final thermostat at the boiler outlet is illustrated in the respective diagrams. These furnish impressive proof of the levelling-out of the steam temperature from the feed control to the final thermostat and of the accurate temperature maintenance at the end of the boiler.

More recent tests have proved that equally good behavior can be obtained with other firing systems. Fig. 11 shows diagrams taken in a 50-MW block-connected set with a Sulzer Monotube steam generator raising 440,000 lbs per hr. The diagrams of test 3 (on the right) show particularly well how little the steam temperature fluctuated even after a sudden load swing of about 40 per cent of full load. It should be considered here that the fluctuating CO<sub>2</sub> content at the time of the load swing made control even more difficult.

Fig. 12 finally shows the steam production and temperature curves of a superimposed plant with a grate-type stoker, reheating and admission pressure control. Here, too, it will be seen that in spite of the sharp change in the load neither the live-steam temperature (line 1) nor the reheat temperatures (lines 3 and 4) have fluctuated much.

When combustion control is used, the storage capacity of the boiler is of the greatest importance. The capacity of the Sulzer Monotube steam generator is comparatively high on account of its large evaporator tubes. It is incidentally essential to know this storage capacity when calculating in advance the behavior of the combustion control system. Extensive tests and theoretical investigations furnished the data required for determining the capacity of the Monotube steam generator.

The maneuverability of the boiler, or in other words its ability to change its steam production promptly, at a fixed final steam pressure, after the adjustment of the firing system, also plays a significant part in the control process. This maneuverability—for the purposes of control theory it is the transfer characteristic of the boiler at constant steam pressure—depends mainly on the time lags occurring in the firing system.

A few diagrams also illustrate load changes with combustion control. As already mentioned, the turbine here takes part in frequency maintenance. Fig. 13 shows parts of curves recorded during tests on a 50-MW block-type plant with a Sulzer Monotube steam generator of 440,000 lb per hr. The firing system was here regulated by hand. Test 1 (left) was carried out at a fairly even load, test 2 (right) with marked load fluctuations. The response levels of the bypass and turbine valves are also entered in the steam pressure diagram. It will be seen that the stoker has succeeded, in spite of the big changes of load, in keeping the boiler pressure

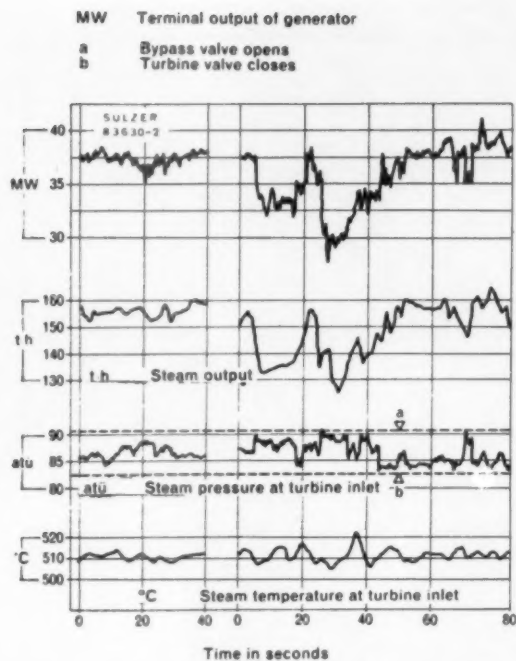


Fig. 13—Behavior during load changes, recorded in a Sulzer Monotube steam generator for 440,000 lb per hr burning pulverized coal. Note the break in charts. Left of break is Test 1; right, Test 2

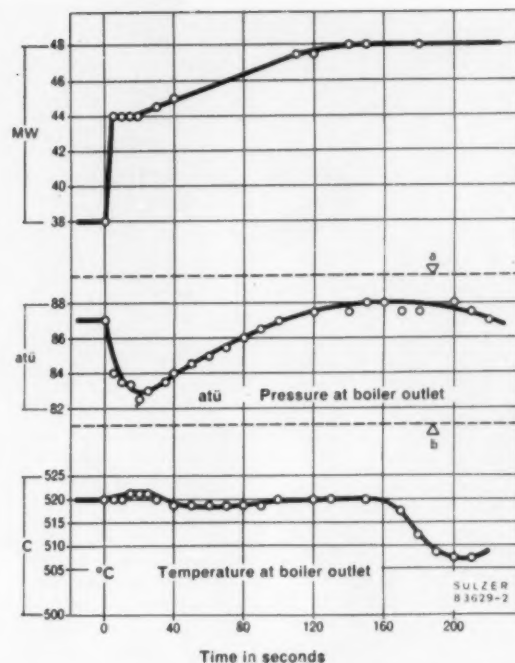


Fig. 14—Behavior after a sudden increase of load, recorded in two oil-fired Sulzer Monotube steam generators for 220,000 lb per hr. The plant participates in frequency control, automatic combustion control

within these two limits, without the valves having responded, by adjusting the firing system. Here too—the live-steam temperature remained within a fairly narrow range in spite of the hand control.

Fig. 14 shows test curves of a plant with *automatic combustion control*, a 50-MW block-type plant with two oil-fired Monotube units for 220,000 lb per hr each, working in parallel. The measurements shown in extract here illustrate the conditions after a very sharp load

swing: the generator loading was raised suddenly from 38 to 44 MW and in the course of the next 100 sec to 48 MW. The immediate drop in the final steam pressure will be noticed. There follows a period in which the pressure gradually rises again under the action of the combustion control system. The response levels of the bypass and turbine valves are again entered in the diagram. In spite of the sudden change of load (the time scale should be noted), neither of these valves responded.

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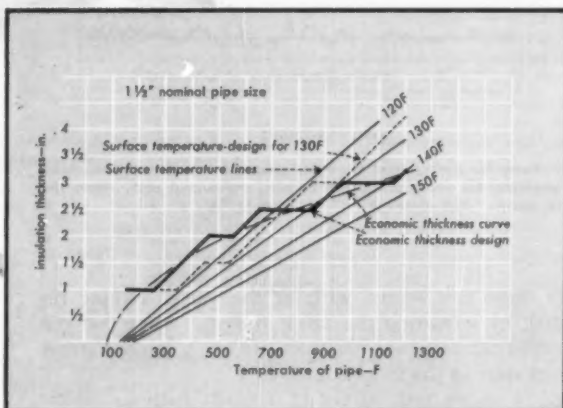
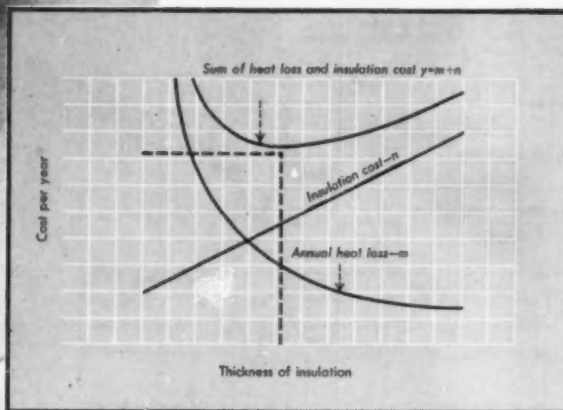
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Above graph shows that as insulation thickness increases, insulation cost increases and heat loss cost decreases. The sum of these two shows the most economical thickness. Greater or lesser thickness costs more money.

In this example, graph shows that below 1000F more insulation is justified than cold surface temperature indicates. Above 1000F less insulation would be used.



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Here's how it works. The annual cost of the heat loss through the insulation is plotted for various thicknesses. Also plotted is the annual cost of insulation. A third curve is then drawn as the sum of heat loss and insulation cost. The economical thickness is found where this third curve reaches its lowest point.

To arrive at the above figures in a given instance requires the following: 1. Cost of heat production per million Btu; 2. Rate of heat loss through insulation in

Btu per unit area per hr; 3. Annual hours of operation; 4. Applied cost of insulation per unit area; 5. Rate of amortization and required return on the insulation investment cost. Items 2 and 4 are available from the insulation manufacturer; others are normally supplied by the plant engineer.

For more complete information, call or write Johns-Manville, Box 14, New York 16, New York. In Canada, Port Credit, Ontario. Ask for reprint of technical article "Select Economic Insulation Thickness."



# JOHNS-MANVILLE





This model was built to determine the best flue design for a precipitator to be built in limited space between existing equipment.

## Plastic Models Improve Dust Collector Results

In the April 1958 issue *Combustion* ran an article on visual aids to duct design by M. J. Archbold. Interest in this approach to a long-standing problem is strong. Research-Cottrell recently held a special press conference at which it demonstrated several of its scaled working models of flue and dust collector arrangements. Below is a report of certain of the findings—all pointing to better overall performance with promises of dollar savings.

**T**ODAY'S 1,000,000 lb per hr steam generators release about 500,000 cfm of flue gas. This gas moves at about 50 fps through most of the ductwork on its way to the stack. But before this gas is discharged to the stack, steps are taken to meet the requirements of air pollution control. Many types of equipment are used from mechanical collectors through cyclone-types to the high efficiency electrostatic precipitators. These last named are almost always present on the public utility and the larger industrial boilers since they remove particles down to the small sizes from 0.1 to 0.4 microns incidental to pulverized coal firing.

The physical problems the electrostatic precipitator has to overcome in removing the suspended dust particles from a stream of 500,000 cfm have been intensified

by the need to quickly throttle down this large mass of hot gas from its roughly 50 fps speed to one of 6 fps. This last named speed is held to be necessary for the electrostatic field to gain enough time to exert its influence upon the particles. But the kinetic energy change caused by a roughly ten to one speed reduction upon a heavy mass of gas tends to express itself as a turbulent force that seriously upsets the uniform movement of the gas across all the surface areas of the precipitator.

### Importance of Flue Design

For a long time engineers have recognized the influence of flue design especially that portion leading to the precipitator upon overall precipitator performance. However, precipitators have always been sold on a "flange to flange" basis in keeping with the usual practice for all other parts of a power plant. Hence the precipitator manufacturer does not design the flues leading to and from the precipitator. In some instances he is shown the flue design so that he can plan the precipitator large enough to make up for an expected turbulent gas flow. Inasmuch as each manufacturer wants to take up as little space as possible and submit the lowest possible bid, short ducts and sharp, right angle turns are the rule.

Research-Cottrell believes that improved flue design will save money for industry. The best way to prove this conviction was to study flue design by means of scaled working models. Such models permit a study of

gas flow patterns as well as a compilation of velocity and pressure profiles. Transparent plastic models were selected because of their workability, ready visibility of smoke and ease of making changes in the models.

#### Quantitative Results From Model Test

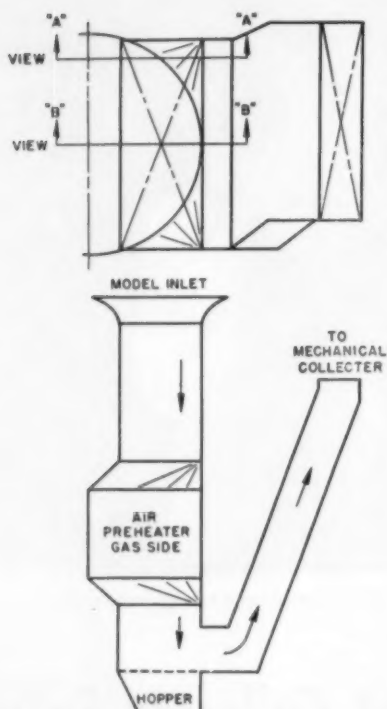
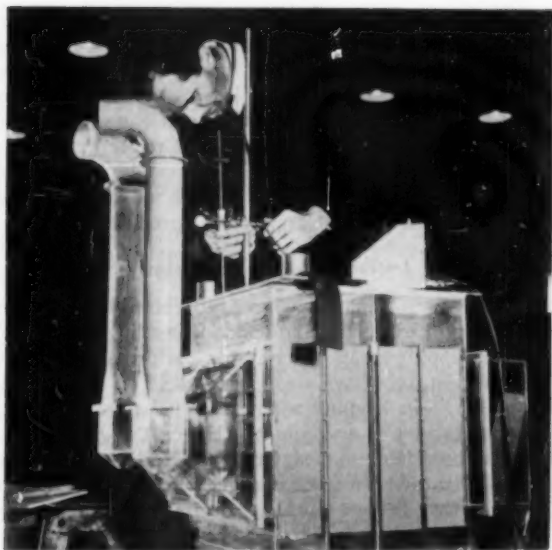


Fig. 1—Initial model, above, has been built to conventional, accepted duct design



The effect of a variation in placement of perforated plates on gas flow through the precipitator is determined by a velocity traverse across the precipitator plates

A very recent test for the Potomac Electric Power Co., Montgomery Co., Md., plant, illustrates what can be accomplished in reducing pressure drop by changing the design of the flue preceding the electrostatic precipitator. Referring to Fig. 1, the model was built to accepted, conventional design. The gas enters at the top of the flue, passes through the round air heater, passes over a wash-down hopper, makes a 145 degree turn into the flue to the mechanical collector. The gas enters the electrostatic precipitator (not shown) after the mechanical collector.

The top two drawings in Fig. 2 show the behavior of the gas (with the conventional design) after it leaves the air heater. Smoke tests (indicated by small arrows) showed considerable turbulence because of the right angle turns, and because of the open hopper.

The first change in the model is shown in the two middle drawings in Fig. 2. The hopper was removed during this test and the left side of the flue was changed from straight to sloping. Less turbulence was noted. The pressure drop was reduced by 15 per cent.

However, an air heater wash-down hopper was required to collect water used in cleaning the air heater. It was agreed with the customer that this hopper was not intended to collect dust. The flue was changed as shown in the bottom drawings in Fig. 2. The turn was rounded and a partially covered wash-down hopper was built retaining the sloping left side of the flue. By experimenting with the design and position of the hopper, the point of minimum hopper circulation was established. The effect of the hopper on overall turbulence and pressure drop was negligible. The pressure drop with the flue as shown in the bottom drawings in Fig. 2 was reduced by an additional 25 per cent or a total decrease from the original design of 40 per cent.

The economic advantage of the design shown in the bottom drawings is considerable. Industry considers that each inch pressure drop is equal to a capitalized investment of \$40,000 to \$80,000. These are savings derived from using a smaller fan, a smaller fan motor and less power over the life of the installation to drive the fan. This does not take into account improved efficiency and decreased cost of maintenance of the mechanical collector and electrostatic precipitator because of more even flow and less turbulence.

Experience indicates that shock flow patterns correlate well and are the same in both models and a commercial sized unit. However, it is difficult to correlate model study pressure drop to full size conditions because the model does not operate at full size Reynolds number. The pressure loss due to surface frictional effects is not known. Therefore, the decrease in pressure drop indicated by the model study cannot be translated directly into a dollar figure.

*Editor's Note: For another view on this correlation problem see Archbold, COMBUSTION, April, 1958, pp. 34-40.*

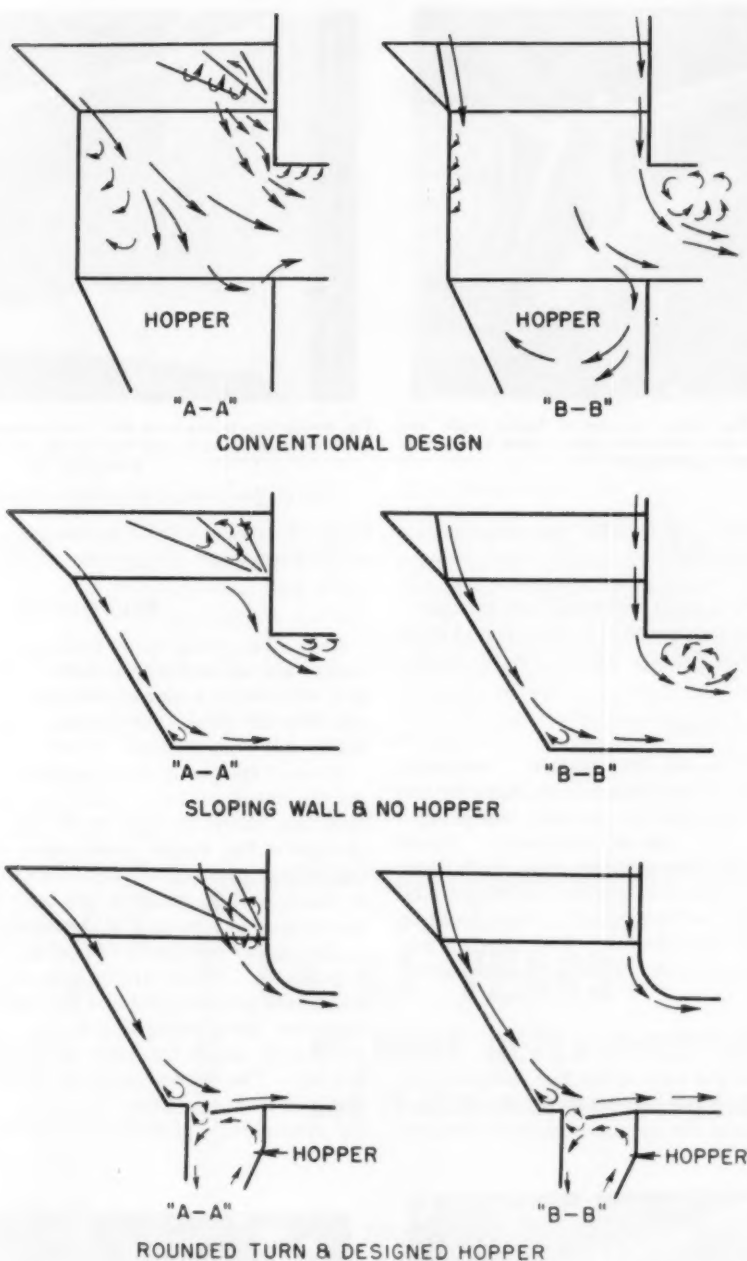


Fig. 2—Flow patterns are indicated by arrows for conventional design, top, and for successive duct changes, middle and bottom showing improvements'

### Possible Dollar Savings

Two years of flue design in working models involving ten models has indicated several areas in which dollar savings to industry can be achieved.

#### DECREASE IN PRESSURE DROP

The greater the pressure drop through the flues, the larger the fan and motor must be to force or induce gas through the system. Industry estimates that a pressure drop has a direct dollar equivalent. Measured in terms

of inches of water, each inch (w.g.) can be capitalized at from \$40,000 to \$80,000. Research-Cottrell has shown by models that it is possible to design flues to reduce pressure loss from  $\frac{1}{4}$  in. to over 1 in. (w.g.).

#### INCREASING CAPACITY PRECIPITATORS

By bringing the gas to be cleaned to the precipitator in a more uniform manner, without turbulence and evenly distributed over all the plates, two approaches to precipi-

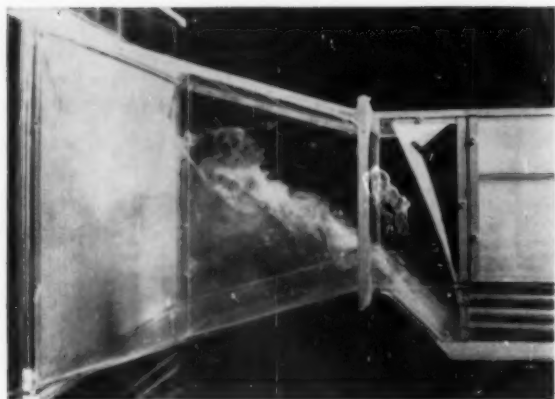


Fig. 3—Original design of flue section between air heater (right) and precipitator (left). Note that only perforated plate is used immediately before precipitator

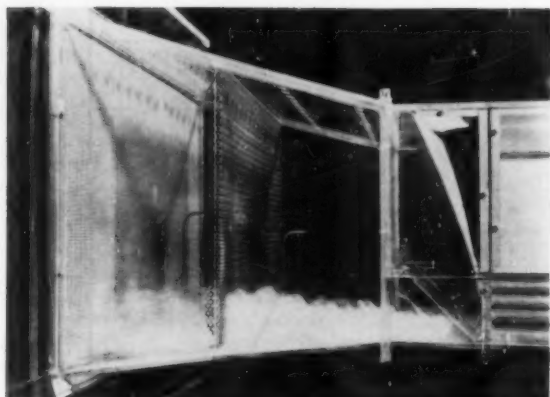


Fig. 4—Air flow is improved after two revisions: eliminating the sharp angle between air heater and floor of flue and by installing a perforated plate in the flue

tator design are possible. (1) Smaller precipitators can be used to attain a given efficiency. (2) A larger volume of gas can be treated in a precipitator of given size. In addition, the extra plate capacity designed into precipitators in the past because gas flow was erratic, is no longer required. The capacity "safety factor" is no longer needed.

#### LOWER CONSTRUCTION COSTS

Model studies have shown that certain components can often be eliminated or their function replaced by less costly devices. For example, by correctly designing a flue, drop-out hoppers can often be eliminated. Model studies showed that the hoppers increased turbulence and pressure drop. Gas currents entered the hopper and stirred up as much dust as it trapped. Dust build-up could be prevented by soot-blowers. The material previously needed for hoppers and the labor of construction were eliminated.

#### SAVINGS IN PRECIPITATOR DESIGN

Although not properly a part of the flue design study, improvements in precipitator design have already been made. Certain baffles in the precipitator itself formerly

used to correct gas flow for example, are now unnecessary, which lowers cost and pressure drop.

#### Basic Findings

As in all research, many findings are basic and negative results are as useful as positive. For example, baffles, flow splitters or vanes have little or no effect on guiding gas flow in three dimensions. Further research with baffles has been stopped.

Most of the problems of gas flow in flues was found to involve shock patterns caused by sharp changes in flow direction, sharp changes in flue cross section and sharp changes in flue shape—from round to rectangular. The importance of maintaining the correct Reynolds number in shock pattern analysis has been found to be of little importance as long as it is above a critical value.

The proper utilization of perforated plates is of utmost importance. Model study showed, for example, that a perforated plate should not be placed in a vertical position over the opening in a hopper. In such a case, the gas flowed under the plate sweeping dust out of the hopper. The open area of the plate is important. The distance from one plate to another is critical, as well as the distance of a plate from the precipitator. The effect

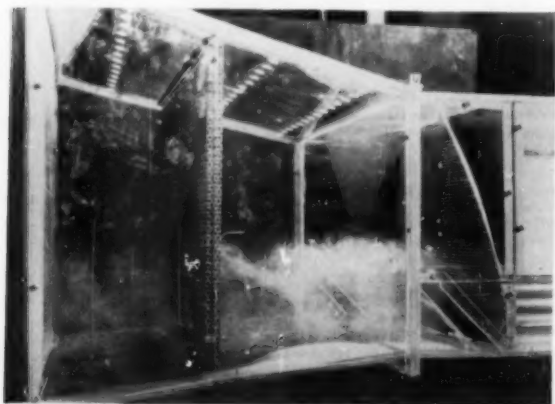


Fig. 5—Smoke stream introduced over bearing of rotary air heater shows turbulence because of void around bearing. Streamlining the end of the bearing reduces turbulence

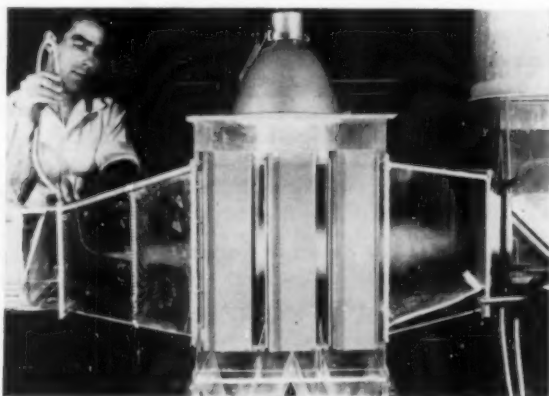


Fig. 6—Complete model includes air heater (left), inlet flue, precipitator with three sections of plates and collection hoppers underneath, outlet flues to stack

of multiple plates was found to warrant further study.

An open space or slot is commonly designed between the perforated plate and the floor of the flue to allow the moving gas to sweep away the dust that might build up at the plate. Studies are now being made of the jet effect of the slot.

Research-Cottrell offers three types of contracts involving model studies. The first requires the building of a model, study of flue design and recommendations without a performance guarantee. The second is the same as the first except that performance is guaranteed. Under the third type of contract, Research-Cottrell undertakes responsibility for design, fabrication and erection of the flues and guarantees performance.

Studies of costs of the models built to date indicate that a model varies from 1-2 per cent of the cost of the precipitator.

### **Wanted: A Gas Turbine Rotating Seal**

Working under contract to the U. S. Army Engineer Research Development Laboratories, Battelle technologists hope to find a rotating shaft seal that will withstand the heat and pressure of a gas turbine nuclear power plant.

The Army Engineers' requirements call for the seal to work efficiently for thousands of hours on a turbine-compressor unit operating at about 25,000 revolutions-per-minute at a peak pressure of about 1000 psi. and a

A model can be built in 6-8 weeks after preliminary drawings have been prepared. An engineer in the model shop scales the drawings down to  $1/16$  the size of the commercial size, or  $3/4$  in. to 12 in. Four technicians cut the parts from  $3/16$ -in. Plexiglas sheets using wood-working power tools such as a saw, sander, joiner and drill press. In a few models  $1/8$ -in. and  $1/16$ -in. sheets are used.

Two test engineers study flow patterns by means of threads, ribbons, ground cork or dust. Most flow pattern studies are made with smoke. Anemometers and pitot tubes are used to take velocity and pressure measurements.

Room air is induced into the models by a fan having a capacity of 5000 cfm at 21-in. w.g. driven by a 25 HP motor. Two smaller blowers are also used.

peak temperature of about 1350 F. Moreover, the seal must be able to keep leakage of the helium working fluid at a minimum. Leakage must be so slight that it will not be necessary to add helium to the circulatory system for a matter of months.

The current goal of the Battelle research team, is to examine the performance of conventional rotating seals subjected to rigorous laboratory experiments. If the characteristics of conventional seals prove unsatisfactory, a longer-range goal would be to find the right combination of materials and design to meet plant specifications.

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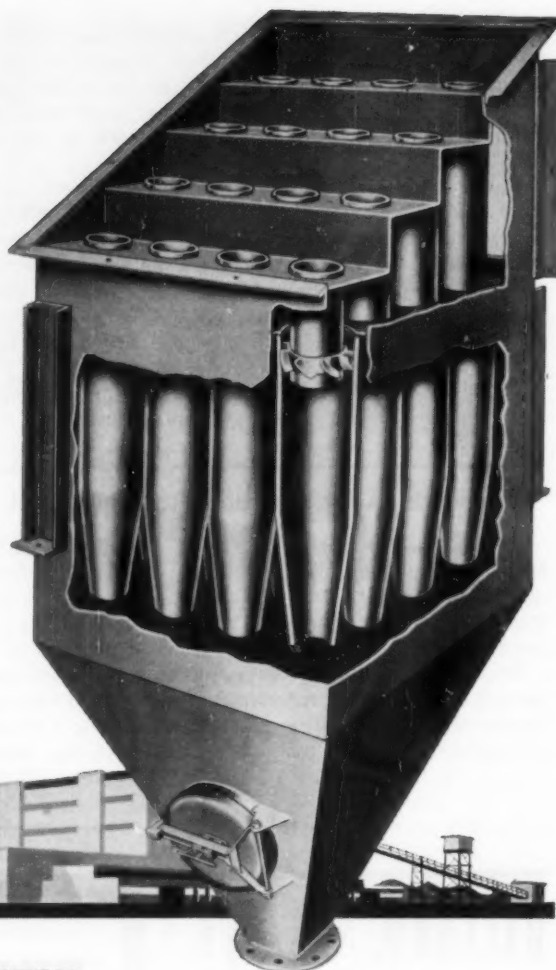
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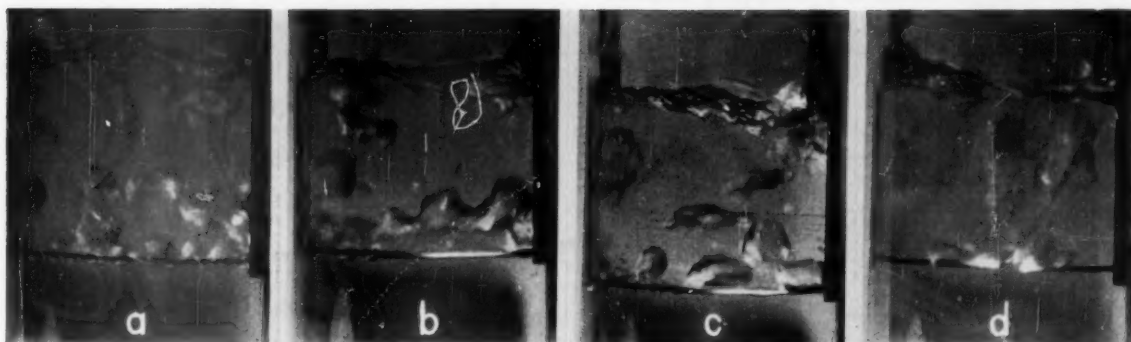


Fig. 4—Boiling over a heated wire. a) at ab. 800,000 kcal/m<sup>2</sup>h the boiling is still nucleate, b)-c) pictures of film boiling over a red-hot surface, d) the heat input has not been reduced fast enough, the wire fuses

## Film-Boiling On Boiler Surfaces

By EDMUND ZIELINSKI

Warsaw

Here is a highly informative account of a basic experiment on the causes for film-boiling on boiler surfaces. The experiment was prompted by the author's conviction that sweeping assumptions were being made on the basis of definitely limited reports.

ENGINEERS in applying the results of scientific research to technical purposes often do not observe the limiting factors of reported laboratory experiments. A newly discovered physical dependency, for example, may become totally invalid for ranges of values differing from the range measured in the experiment.

This paper is aimed at clearing up the question of film-boiling in steam boilers. It is a matter on which incorrect applications, as described above, were reported frequently. The nature of film-boiling, as another form of the process of which the nucleate (or bubbling) form is the well-known first one, was indeed examined in laboratory experiments. It was investigated by physicists. From their reports we know that film-boiling occurs at high thermal loads of the heated surface, a marked decrease in the rate of evaporation being caused thereby from the insulating properties of what seems in effect a surface-bonded vapor film. But these reports were not a sufficient basis to conclude that: "in modern high-rate steam boilers an overloading of the heated surface may induce the film-boiling, with an immediate drop of the boiler-output. . ."

### The Fundamental Conditions

Such an interpretation errs from two points. Supposing at first, that it were really possible for the vapor-film to cover an essential part of the boiler surface, an immediate overheating and damage of the surface parts, exposed to high temperatures on the flame side should develop. This is easy to prove by means of figuring the wall temperatures of a tube, covered on the evaporating side by a layer of stagnant vapor, with its very high resistance to heat conduction. Yet such experience does not occur. The other questionable point

is what conditions make the formation of film-boiling possible at all? This point we shall discuss.

From the known results of laboratory investigations [1, 2]\* we may conclude that the transition-point from nucleate boiling into film-boiling is fully determined by the value of heat flux through the heated surface, and that these values differ for varying pressures. The references quoted above represent mainly experiments, performed at (or below) atmospheric pressure. But there are other reports [3, 4, 5, 6] which indicate the position of the transition-point also for pressure ranges common in modern boiler practice.

Another essential point associated with the mechanism of film formation is the overtemperature of the heated surface. Raising the heat flux in the range of the nucleate stage, the temperature of the evaporating surface increases but slowly above that of the boiling water in bulk. This temperature difference reaches about 25 C (75 F) at the transition to film boiling—which point is at the same time the border of the nucleate boiling range and represents also the maximum possible heat flux for a given pressure. This temperature difference was even taken in several reports as the basic coordinate to plot the process in diagrams. It seems, however, that the heat flux should be taken as the causal factor of film formation, and that the herewith connected temperature difference be considered as rather a consequence of structural forms of the steam-water mixture near the surface.

On the other hand once the vapor film is formed it is obvious that the resistance of the vapor layer to heat conduction will cause, immediately after the trespassing of the transition point, a sharp decrease of the heat transmission (heat flux). This is an essential feature of the process: in the first stage it is possible to control

\* Numbers in brackets refer to Bibliography at close of article.

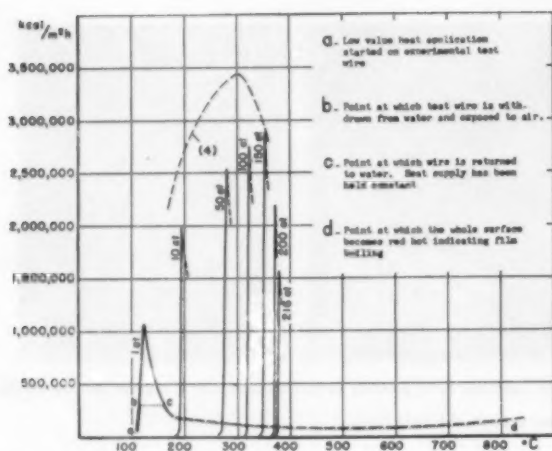


Fig. 2—Heat flux against surface temperature for higher pressures. Curves recalculated from the reports [1] [4] [5] [6]. The maxima of nucleate boiling for 10–216 atmospheres evaluated according to Krujilin's formula, deteriorate slightly from Kazakova's results [4]

all the factors involved by arbitrary variations of the heat flux. Beyond the transition point, however, the process runs by itself without our control. This precludes any possibility of a forced return to the nucleate stage once the process has passed over the transition point.

#### Required Heat Input

These implications are easy to examine on diagrams Figs. 1 and 2. For boiler practice the interesting factor is the tube wall temperature, taken as it occurs and not as a temperature difference over the boiling water. Thus the relationships in Fig. 2 were plotted against a temperature computed from the saturation temperature at the given pressure plus the temperature difference of the nucleate boiling.

The performed investigations may be accurate only to a certain degree (differences between laboratory conditions and technical industrial equipment should be taken into account), nevertheless the represented results seem to determine with sufficient exactness the range of heat fluxes which were necessary to induce a formation of film boiling. These values are in every case above 1,000,000 kcal/m<sup>2</sup>h (400,000 Btu/sq ft hr) at atmospheric pressure and may rise to some 3,000,000–4,000,000 kcal/m<sup>2</sup>h (1,000,000–1,500,000 Btu/sq ft hr) at pressures at which modern industrial boilers are operated.

Now let us talk about heat fluxes which do really occur over the heated surface of a steam boiler. Theoretical computations may give the following maximum possible flux values:

	kcal/m <sup>2</sup> h	BTU/sq ft hr
From convective heat transfer.....	70,000	( 25,000)
From the radiation of gases.....	45,000	( 16,000)
Direct radiation in the combustion chamber.....	300,000	(114,000)
Total	415,000	(155,000)

The value of 415,000 kcal/m<sup>2</sup>h should be taken as a local maximum for such points of the boiler surface which are exposed to all the three sorts of heat transmis-

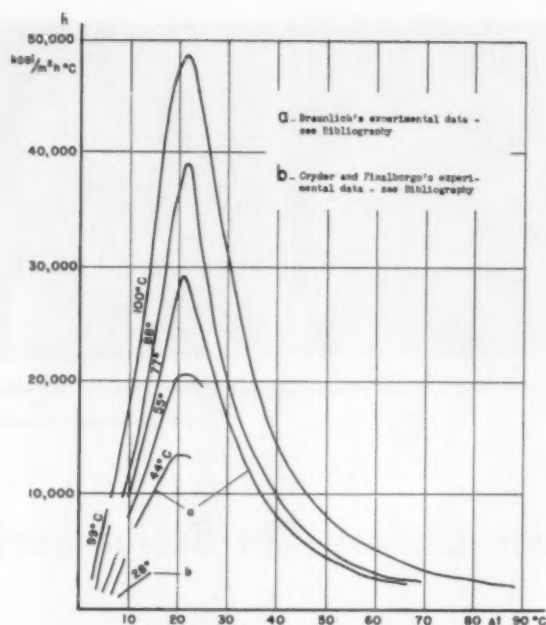


Fig. 1—Coefficient of heat transfer on boiling surface at atmospheric and several reduced pressures. "a"—Braunlich's [1] and "b"—Cryder and Finalborg's [2] experimental results. The curve for 1 atmosphere redrawn for the heat flux and with extrapolated film-boiling branch is shown in Fig. 2

sion simultaneously; besides, it was calculated with maximum values of all factors involved.

Average values of heat flux for the whole boiler surface would be considerably lower. Operational test and measurements on boilers indicate the rate of steam production of about 250 kg/m<sup>2</sup>h (50 lbs/sq ft hr) as a high average value for modern boiler surfaces exposed to direct radiation of the flame. That means, according to the pressure, about 80–100,000 kcal/m<sup>2</sup>h (30–40,000 Btu/sq ft hr).

Returning back to Fig. 2, we see that these values of heat flux lay far below the maximum points of the nucleate boiling stage. And thus, as the trespassing of the transition-point was determined as a condition without which the formation of film boiling were impossible, we should not expect film boiling at all in any part of a steam-boiler surface especially at the high pressures now commonly in use.

Such a result of the analysis was however unexpected even by the author, whose investigations had been undertaken with the hope of explaining some cases of overheating of the boiler-tube material by the mechanism of vapor-film formation inside the tube. As such cases of local overheating resulting in swelling and even breakage of the tube are well known to every boiler operator and do really occur quite frequently, further experiments were undertaken to clear up the problem.

#### An Unexplained Problem

It is relatively easy to arrange a laboratory device on which film boiling under water at atmospheric pressure can be induced and demonstrated. A short piece of wire between two electrodes, submerged in water and heated electrically by low-voltage alternating current may do the task. The key-point to be observed is to calculate

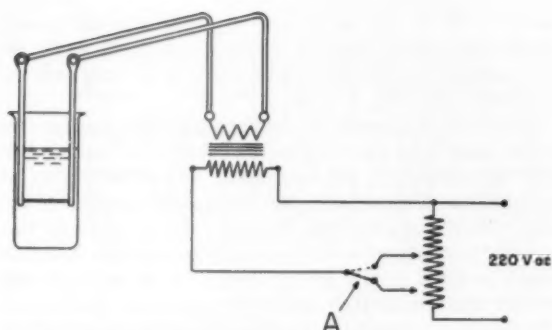


Fig. 3—Simple laboratory device for experiments with film boiling

an appropriate relation between the electric input and the surface area of the wire, in such way that a heat flux of a minimum of  $1,000,000 \text{ kcal/m}^2\text{h}$  may be obtained. (A wire 1.8 mm dia, 66 mm long, fed by transformer 220/6 V, 1000 W has been used by the author.) Furthermore a switching device should be provided (A in Fig. 3) enabling a momentary reduction of the current at the moment when film boiling begins, otherwise the wire will fuse. For experiments of the same kind to be performed at high pressures, it would be much more difficult to arrange a simple apparatus. We may, however, try to interpret the results obtained at atmospheric pressure according to the curves of Fig. 2.

It is obvious that such an experiment reproduces but very inadequately the real conditions existing in actual steam boilers. Nevertheless it should be of interest to see how the process of growing evaporation proceeds from nucleate boiling. At first the rate of evaporation is moderate with characteristic columns of steam bubbles, rising always from the same points of the heated surface—then, a very live stream of great steam bubbles—and at last, at the moment of trespassing the maximum flux, a red glowing part of the wire, indicating the formation of a surface bonded vapor film. This last occurrence would be just the right duplication for the experience of a locally overheated boiler tube. But, as confirmed by this crude experiment, it can be attained only at heat flux values of about  $1,000,000 \text{ kcal/m}^2\text{h}$  (compare Fig. 4, a-d p 47).

#### Experimental Findings

Another way to induce film boiling, however, appeared possible during the described experiment. With the heating current regulated to a relatively low value—corresponding to about  $300,000 \text{ kcal/m}^2\text{h}$ —the wire was drawn from the water for a short while. Being in air, the wire became dry and its temperature rose. Then the wire was submerged again (the current supply maintained at the same level) and after a few seconds the whole surface became red hot, which indicated the formation of film boiling. The whole series of processes took place on the way a-b-c-d (indicated as a dotted line on Fig. 2), i.e., within a range of heat fluxes, which are possible in actual steam boilers.

The causal factor in this process was obviously the temporary break of contact between the heated surface and water. Such cases may be imagined in boiler practice when certain conditions of circulation would facilitate the formation of great steam-props in piston form travel-

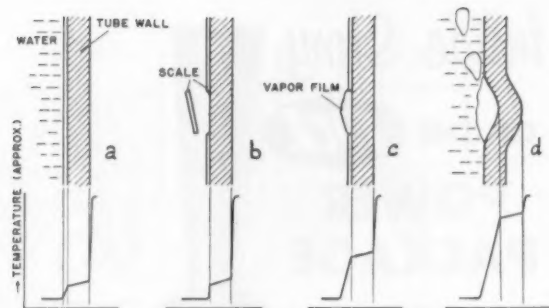


Fig. 5—A reconstruction of a surmised overheating of a scaled surface

ing slowly along the riser tube. According to the experiment the danger remains even after the surface has been covered again with water.

#### Pinpointing Film-Boiling

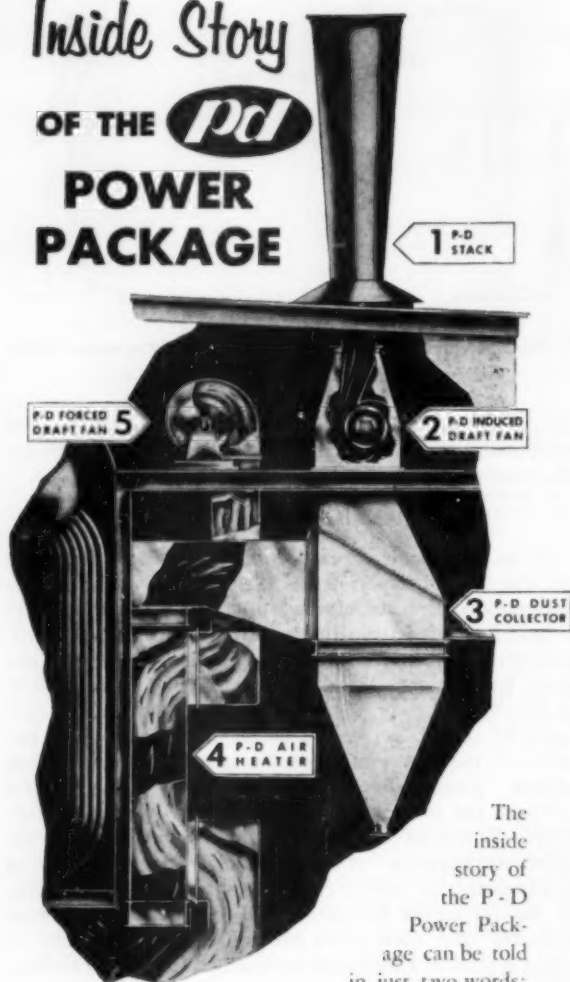
So we may draw the following conclusions, based on the graphs and experimental observations: As long as nucleate boiling is maintained independently of the value of heat flux but within the indicated range, an overtemperature of the tube wall on the evaporating side could never become greater than  $25^\circ\text{C}$  ( $75^\circ\text{F}$ ). A formation of film-boiling over the whole, or even over essential parts, of the boiler surface seems to be impossible because of the range of heat fluxes attainable in steam boilers. Such boiling may, however, occur on isolated parts of the surface as a consequence of a temporary break of contact with water caused, for instance, by great steam-props. A consideration of the problems of circulation as well as the fact that this one possibility of film-formation requires relatively high heat fluxes indicates that such cases are most likely to occur at upper points of riser tubes exposed to furnace radiation. At such points the "slug stage" of circulation (steam props in piston form) may be expected to develop at high load rates of boiler operation.

There remains still another way to explain the possibility of vapor-film formation on boiler surfaces. It may be deduced logically, although as yet not proved by experiment.

By the above mentioned mechanism of film formation, the temporary break of contact with water was taken as the causal factor. That argument seems to be correct only in a descriptive sense. Going into the details of the process we should consider the following sequence of facts: the break of contact with water means a cessation of cooling; the surface, heated steadily from inside, gets to a temperature higher than the saturation-temperature  $+25^\circ\text{C}$ ; when at this moment the water flows again over the surface this is just the origin of vapor-film formation. The last fragment may be compared with the Leidenfrost's effect known in physics (prolonged evaporation of water drops on hot iron plates). We should, therefore, say precisely that film boiling occurs in cases where water comes into contact with a dry surface, which has been heated to a temperature a given amount of degrees higher than the boiling point.

The above set of circumstances may be found on a scale-covered boiler surface when any one outside factor

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causes a bit of the scale-layer to split and fall away. Using well known thermal conductivity coefficients, we may evaluate the temperatures, existing at scale covered boiler surfaces, Fig. 5, a, b.

Inspecting the inside of a boiler tube after damage, we find in most cases the scale on the overheated and swollen part detached from the tube wall. We explain that as the obvious effect of the stretching and bending of the tube material during the damage. Now, perhaps this is quite the contrary and a reasoning in reversed direction would be right; viz., an accidental break up of a part of the scale was the cause of vapor-film formation, which in turn caused the overheating and damage of the tube wall, Fig. 4, c, d. This interpretation would represent the other possibility of film-boiling occurrence in steam boilers and is the one that may be found rather in the lower parts of riser tubes where good conditions of water-circulation prevail and a slug stage of the steam-water mixture should not be expected.

## Author's Statement

"The simple experiment with film boiling, described above, showed another interesting phenomenon for which the author did not find as yet an appropriate explanation. In some cases the film boiling, once formed, recedes slowly going back again into the nucleate form although the heat supply (electric input) remains constant. Examining this second transition with an un-armed eye, we see a strange effect of a discontinuity of the process. It looks like as when at a cinema-performance several pictures of the film strip had been cut out. The way for this process from film boiling back into the nucleate stage along the curve, Fig. 2, through the maximum point being impossible, according to the relatively low value of heat input, it probably has been shunt over to the left branch of the curve on the way d-c-b-a. Perhaps high-speed photographic methods of investigation might be of use to explain the fragment of the way from point c to b. It seems to be another process running by itself, without the possibility of control from outside."

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- [5] Krujilin, G. N., *Izvestia Akademii Nauk SSSR, OTN*, No. 7, 967-980, 1948 and No. 5, 701, 1949.
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## AEC Invites Proposals from Industry

The AEC is calling upon industry to help develop reactor components which are exposed to liquid metal coolants and suitable for operation under conditions necessary to provide the high steam temperatures and pressures required in modern electric generating stations. The development program will complement work now being conducted by the Commission on advanced sodium cooled reactor systems. Proposals must be received by May 26, 1958.

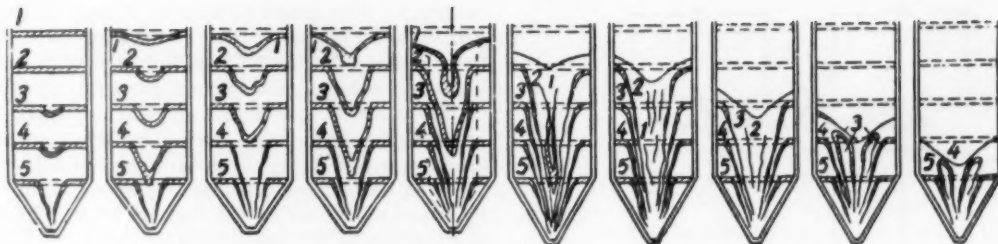


Fig. 1—The outflow of material from a bunker (according to the tests conducted by Luft)

## The Fight Against Fuel Clogging in Bunkers\*

By ENGINEER M. S. MASLENIKOV

*Editor's Note: The following comment on this article is a direct translation of the views of the editor of Teploenergetika, the Russian publication from which this article has been taken. It needs no further commentary.*

Up to this time many power stations are experiencing serious difficulties as a result of fuel clogging in sleeves and bunkers, stopping up crushers, sticking conveyor belts and the like. M. S. Maslenikov's article reports of some ways of decreasing the possibility of fuel clogging in bunkers and sleeves. However, this question has not been treated fully. For example nothing is mentioned about crushing the crests in bunkers by means of compressed air. This method is widely used outside the USSR and at several of our coal-tar chemical plants. According to the personnel of our power stations vibrators in the form of electric motors with a de-balance perform better than electromagnetic vibrators. The article mentions negative results on the use of vibrators in unloading milling turf cars. However, no reasons are given as an explanation. Vibrators can give a positive effect only by adhering to a series of conditions. The author's explanation why fuel clogging decreased after rectification of the sleeve, as shown in drawing 3, is not sufficiently substantiated. In printing Mr. Maslenikov's article the editor surmises that it will provoke corresponding comments from operating personnel and that they will share their valuable experience in not only eliminating fuel clogging in bunkers and sleeves but also in eliminating other fuel feeding difficulties.

LOOSE, flowing solid material in contrast to a liquid stream creates a variable pressure across the bottom of a vessel.<sup>1</sup> This variation of pressure from point to point is due to the uneven weight of the moving column of material passing through the vessel. The exact value of the pressure at any given moment may be expressed by the logarithmic curve law,

$$y = a.z \left( 1 - \frac{1}{l \frac{bx}{z}} \right) \quad (1)$$

where:

- $y$  = pressure at the bottom of the vessel
- $x$  = height of the layer of material above the bottom
- $z$  = The relation of the cross-sectional area,  $F$ , at the bottom of the vessel, to the vessel's perimeter,  $V$
- $a, b$  = Constant coefficients, depending on the specific weight and the internal friction of the loose flowing material.

The above formula also establishes the fact that the quantity of loose flowing material coming out through the lower opening of a bunker similarly to the pressure upon the bunker's bottom opening, does not depend upon the specific layer height as would be the case for a liquid.

### Study of Flow Patterns

A number of tests have been run which show the characteristics of the "flow" of free flowing material. Fig. 1 presents certain data from the experiments by Luft<sup>2</sup> observing the flow of sand tinted in various colors by layers. Similar tests to these depicted were run. In the first instance the material situated directly over the opening comes out after which a vertical channel appears over it. The experiments confirmed the fact that the "flow" is determined by the size and shape of the exit opening and not the height of the column of the flowing material. The design of the projecting device, that is, the feeder, also has an influence on "flow."

### Bunker Exit Cross Section

From the formula (1) it follows that with the same height of layer material the pressure,  $y$ , at the bottom of the bunker varies with the relation,  $F/V = Z$ , or the shape of the bunker or sleeve, that is, its exit cross section,  $F$ , to its perimeter,  $V$ . Consequently it pays to give a bunker sleeve a shape with  $Z$  as large as possible.

For circular and square sections  $Z = a/4$  where  $a$  is the side of a square or the diameter of a circle. Dividing a bunker (sleeve) by means of screens or partitions de-

\* Translated by V. A. Ferencko, Combustion Engineering, Inc., from the Russian publication, *Teploenergetika*, 1957.

<sup>1</sup> *VDI*, 1895, 39, 1045.

<sup>2</sup> E. Luft, *Druckverhältnisse in Silozellen*, Berlin, 1920, IV.

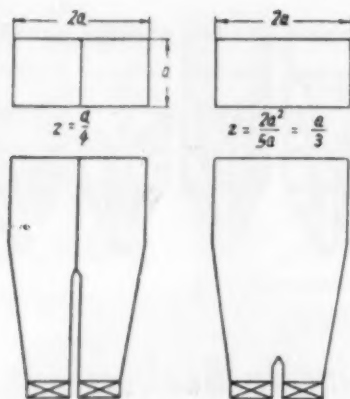


Fig. 2—The influence of intermediate shells on the parameter  $Z$

creases the value of  $Z$  and hence the "flow" condition of the material, Fig. 2. Where, however, it is deemed necessary to so divide a bunker into two outlets the joint sleeve comprising the division should be as small a length as possible, Fig. 2.

### Clogging

Clogging which produces crest formations results from (1) physical properties of the material, foremost among which are the coefficients of internal and external friction, (2) size and shape of lumps, (3) size and shape of the bunker or sleeves. Since size and shape of bunker or sleeve is a matter of design certain precautions at this point can be taken to alleviate clogging.

Crest formations as the result of clogging become more probable as the span of the crest decreases, as the weight of material comprising the crest reduces, and the crest's curve radius decreases. This last, the crest curve radius, will be smaller with inclined bunker partitions than with vertical ones. Similarly bends on sleeves assist in crest formation and they should be eliminated where possible or greatly smoothed. In one turf power plant where frequent clogging had been encountered during cold weather a change of sleeve profile, Fig. 3, completely removed the problem.

Fuel clogging in bunkers can occur because of the appearance of the force,  $S$ , creating a supplementary compression of the fuel. An unloading pocket properly placed in the bunker, Fig. 3, can probably eliminate or remove the influence of this force. In fact, the effectiveness of this unloading pocket will be proven in the near future in one of the bunkers of a large power plant.

Freezing, however, represents the major cause for fuel

hang-ups. One plant in seeking means of eliminating turf build-up in bunker sleeves widened these sleeves at their bottom for one of the boilers, Fig. 4. The turf build-up, however, did not progress far enough to fall of its own weight and fuel clogging remained as formerly. Bulky pulverizing equipment has been suggested as one way of fighting the difficulties imposed by freezing fuel. It seems more expedient, however, to try portable equipment for heating the fuel by high frequency currents applied at the point of fuel clogging.

Up to this time fuel clogging in bunkers is combatted by physically beating the bunker walls or breaking through the clogged fuel with bars and pokers. Putting aside the appreciable labor costs such work is often very dangerous since the work must frequently be carried out from within the bunker. The designer is not especially concerned about such work and forgets, usually, to provide conveniences such as manholes in the bunker walls.

Recently electric vibrators such as those used in the construction industry have been employed for the task of breaking up clogged fuel. These vibrators usually have an electric motor with an unbalance or a cam drive to produce the required jolts and bangs or sometimes electromagnets are used whose cores effect short vibrations upon closing and opening of electric circuits. Vibrations are transmitted either directly to the bunker shell or to a steel plate located on the interior shell of the bunker in the case of reinforced concrete bunkers.

In the USSR the unbalanced electric motor is most frequently selected whereas the electromagnetic vibrators have found wide acceptance elsewhere. The electromagnet possesses the characteristics of smaller vibration amplitudes (micro-vibrations) high frequencies, no lubrication requirements. For most cases a 50-cycle frequency suffices. Vibrations from the electromagnet carry into the material approximately in a rectilinear manner. Their intensity diminishes rather quickly and was found to do so particularly in experiments with sand. With this material the penetration of vibrations was limited to 1.5 meters.

### The Effect of Vibrations

As a working tool vibrations that are set up within a material decrease the internal friction between the individual particles and hence create better conditions for the material's movement in the sleeves and bunkers. In the case of sand the effect of vibrations on the natural angle of inclination were found to vary with the frequency of vibration, its amplitude ( $S = 2a$ , where  $a$  is amplitude) and the time duration of the vibrations. In general the flowing material—size of the lumps, moisture content, quantity of frozen moisture—exerts a special

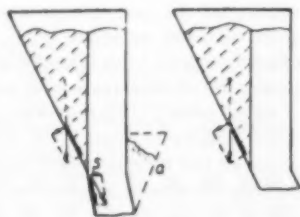


Fig. 3—The influence of breaks of a sleeve on fuel clogging in a bunker

Fig. 4—Widening a sleeve under a bunker



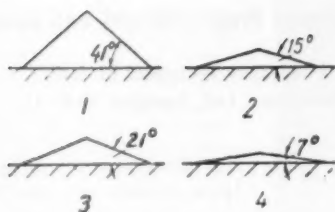


Fig. 5—The effect of a vibration on a natural angle of a sand slope (1) without vibration; (2) 5 sec, 50 hertz, 0.75 mm range; (3) 5 sec, 100 hertz, 0.2 mm range; and (4) 20 sec, 100 hertz, 0.5 mm range

toll upon the vibrator's effectiveness. Therefore the same effect cannot be expected in handling sand as against lump turf. One turf power plant, for example, reported no success for a vibrator employed as an aid in unloading frozen cutting turf.

#### Other Bunker Problems

Erratic fuel feeding from bunkers is not confined to fuel clogging. Certain attempts to achieve a smooth, uniform flow of fuel<sup>3</sup> have been made and Fig. 6 illustrates one. The bunker with the vertical shells has a 3 by 3 meter cross-section and was equipped with four feeders (vibration spouts) separated from each other by saddle shaped cross pieces. Vibration blades, electromagnetic in operation, were located over the spouts. These vibration spouts ran light under smooth working conditions since the dust remained in the bunker. Once the vibration blades are set in motion the dust begins to "flow" towards the spouts. By gradual engagement of the blades (the rear first and then the following) a uniform emptying of the bunker occurred.

Vibrations lighten and regulate the unloading of bunkers and lower the power costs. If the power needs of an apron conveyor are compared with those of a vibration spout the following differences develop for a 100 ton per hr productivity on a 900 mm wide feeder:

	Apron Feeder	Vibration Spout
Length, mm	1800	1500
Working output, watts	2500	450

Fig. 7 shows the productivity of vibration spouts on layer thickness and vibration range.

#### Non-Soviet Solutions

Other non-Soviet means of combatting the clogging of "free flowing" materials in bunkers are so-called "bunker blocks." These bunker blocks consist of a steel plate,

<sup>3</sup> *Chemie-Ing-Techn*, 1956, No. 4.

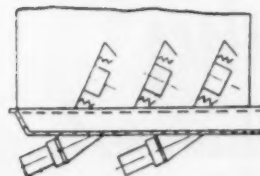


Fig. 6—Arrangement of vibrators in an industrial bunker

along the perimeter of which is fastened a 12 mm thick rubber diaphragm by means of a flange. Compressed air with a pressure of 2-4 atmospheres is fed through an opening in the plate along a tube. The diaphragm takes on the shape of a block and puts pressure on the fuel.

The diaphragms are usually made having a rectangular shape and measuring 800 × 1000 mm. Under pressure of the 4 atmospheres a similar device creates a force of about 32 tons, sufficient to crumble the clogged fuel. In cases of necessity the diaphragms have a round shape with a diameter of 600-1000 mm.

In order to prevent a diaphragm break in the center of the plate a safety valve is connected with the diaphragm by five chains. These chains open the safety valve upon reaching full capacity of the bunker block. The bunker blocks position themselves along the shell in a staggered arrangement. Control of the bunker blocks is executed on a special panel located near the bunker by means of a special press button control device.

The compressed air must be cleaned of moisture and grease before entering the block to avert corrosion of the metallic parts and damage of the rubber.

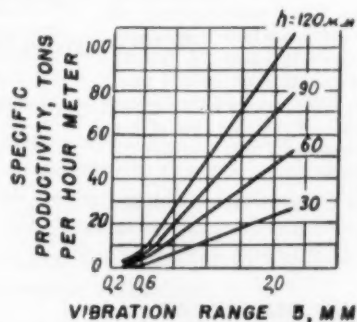


Fig. 7—Thickness of the layer of material against which vibration spouts must work exert a definite influence upon the possible depth or range of effectiveness that individual vibrations can produce on output.

## Emission and Absorption Studies of Hydrocarbon Combustion Products

The National Bureau of Standards has made a spectroscopic study of the infrared radiation from combustion gases under the sponsorship of the Wright Air Development Center. This work was done by G. A. Hornbeck and L. O. Olsen of the combustion controls

laboratory to provide information that may make possible the measurement of jet-engine and gas-turbine exhaust temperatures. Ultimately such data should aid in the development of a flight-type radiation pyrometer to indicate and control the temperature of the hot gases which form the working medium for jet engines.

Temperature must be determined from some property of the exhaust gas, measured by an outside instrument.

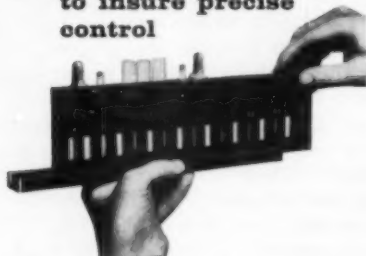
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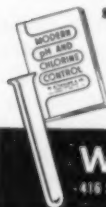


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## **Abstracts from the Technical Press—Abroad and Domestic**

(Drawn from the Monthly Technical Bulletin,  
International Combustion, Ltd., London, W.C. 1)

### **Fuels: Sources, Properties and Preparation**

**A New Insight into the Chemical Constitution of Bituminous Coal.** J. Karweil. *Glückauf* 1958, 94 (Jan. 18), 125-8. (In German.)

The results of recent investigations into the chemical structure of coal by means of infrared, nuclear and electron-resonance spectrometry are reviewed. These methods have made possible the measurement of certain chemical structure parameters of coals. Although quantitative data are not yet available and the question of the degree of condensation of the aromatic nucleus is still left unanswered, it is believed that the new methods will make this possible in due course. Some clarification of the nature of the peripheral groups and the changes they undergo during coalification has already been obtained.

**Coal Desulfurization in a Fluidized Carbonizer.** J. K. Jacobs and J. D. Mirkus. *Ind. Eng. Chem.* 1958, 50 (Jan.), 24-6.

Studies were carried out to reduce the sulfur content of high-sulfur Illinois coal used for steam generation to reduce the sulfur content of the flue gases. Results obtained by low temperature fluidized carbonization showed that sulfur removal increased with reduction of particle size, increase of residence time, higher fluidizing velocities and higher temperatures up to 800 F, but air and steam content of the fluidizing medium had little effect. The sulfur content of the char was reduced to half of that of the coal, organic sulfur being less reduced than pyritic and sulfate sulfur.

### **Mechanical Handling**

**Handling Coal on the Public Service System.** R. A. Baker. *A.S.M.E. Preprint* 57-A-272 1957 (Dec.), 9 pp.

The development of coal handling plant at various stations of the Public Service Electric and Gas Company is described. At Burlington station's No. 7 unit the usual indoor bunker with a storage capacity for 24-48 hours operation has been omitted and replaced by an active outdoor storage pile from which the coal is transported to four-hour bins immediately above

the pulverizers, the filling of the bins being actuated by electronic probes.

**Tensioning Conveyor Belts.** Anon. *Engineering* 1958, 185 (Jan. 24), 102.

To avoid the necessity of tensioning the belt to give sufficient friction for the drive and to enable a greater tractive force to be applied an auxiliary belt is provided which is in contact with the outer surface of the conveyor belt during its passage around the driving drum. The tension of the auxiliary belt is so adjusted that it presses the conveyor belt against the drum to ensure drive without slip.

### **Steam Generation and Power Production**

**The 1957 Status of Steam Properties.** F. G. Keyes. *A.S.M.E. Preprint* 57-A-228 1957 (Dec.), 17 pp.

The present state of knowledge of the properties of steam and water up to 15,000 psia and 1500 F, the discrepancies between measurements made in various laboratories and

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between theoretical and observed data and the difficulties involved in such measurements are reviewed. Required are tabulations of thermodynamic quantities, thermal conductivity, viscosity and Prandtl numbers, standard specific heats and information on relaxation time either by velocity from sound measurements or some other methods. The investigations currently undertaken in various countries are summarized and the added difficulties arising from the conversion of one temperature scale to another pointed out. A temperature scale project is therefore undertaken by the U. S. Bureau of Standards.

**Experimental Investigation of Heat Capacity of High-Parameter Water and Steam.** D. S. Rasskazov and A. E. Sheindlin. *Teploenergetika* 1957 4 (Nov.), 81-3. (In Russian.)

A description is given of an experimental installation and the results obtained with it in the determination of the heat capacity of water and steam in the pressure range of 300-500 atm. and temperature range of 280-685C.

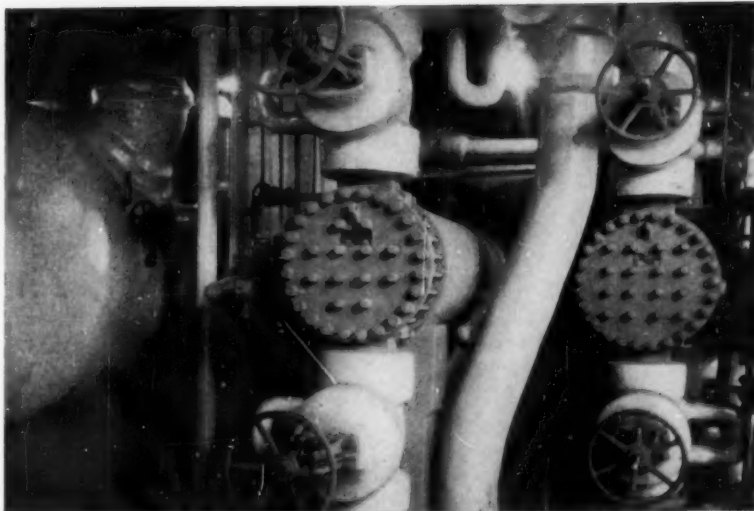
From *C.E.G.B. Digest* 1958, 10 (Feb. 15), 358.

**Computing Stresses in Pipe Systems.** Anon. *Fluid Handling* 1958, (Jan.), 5-6.

A program has been worked out by Ferranti Ltd. for computing stresses in three-dimensional multi-anchor steam or hydraulic pipe layouts. Pipe lines with up to nine anchors can be dealt with and because of the short time required for the calculation it may easily be repeated for different layouts, pipe diameters or additions.

**550 MW Reheat Boiler.** Anon. *Elect. Rev.* 1958, 162 (Feb. 14), 301-2. *Elect. Times* 1958, 133 (Feb. 13), 260.

The C.E.G.B. will order from I.C.L. the boiler for the first unit of a power station in the neighborhood of Doncaster as soon as the consent of the Minister of Power for the establishment of the station has been obtained. The boiler is rated at 3750 klb/h, at 2400 psi and 1055/1055 F and will contain two furnaces each sub-divided into two sections, one furnace controlling the superheated steam, the other the reheated steam temperature. The furnaces have a width of 68 ft, a depth of 28 ft and a height of 100 ft with the drums at a height of 150 ft above ground. Water circulation is of the assisted type, the pumps being driven by water-immersed motors. There are four mills to each furnace, each of 50 t/h capacity. Coal consumption will vary with quality (ash



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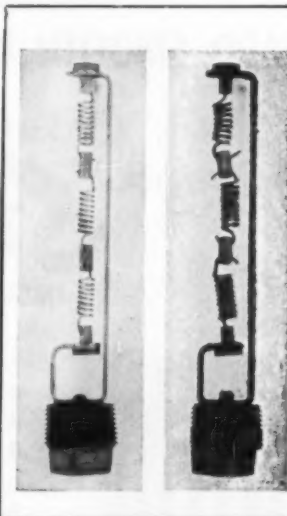


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To demonstrate what corrosion can do in steam and condensate return lines, we show here "before" and "after" unretouched photographs of NDHA Corrosion Testers. This is a test\* developed by the American Society for Testing Materials in cooperation with the National District Heating Association. Bird-Archer supplies and analyzes these testers. Photo at left shows a Tester before installation. Photo at right shows a Tester after it had been installed for 60 days in the return line. (\*Standard Method of Corrosivity Test of Industrial Water, NDHA Method, ASTM Designation 935-49.)



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contents of 6-30 per cent and moisture of 4-20 per cent) between 205 and 220 t/h. The thermal efficiency of the boiler will be 90 per cent.

**Heat Exchange in Steam Generators as a Function of the Load.** K. Becker. *Energie* 1958, 10 (Jan.), 22-31. (In German.)

A mathematical analysis is presented of the influence of load variations on the heat exchange in the radiant and convection parts of a boiler, on superheating of steam and on boiler efficiency.

**The Dynamic Characteristic of Once-Through Boiler.** A. A. Davidov, E. I. Schmukler, A. P. Zhivotov and K. A. Rakov. *Teploenergetika* 1956 (11), 19-25, D.S.I.R. Translation CTS. No. 409.

A method is described which permits an approximate calculation of the dynamic characteristics of a once-through boiler during changes of load from thermal calculations for variations in water and fuel flow up to limits of 20 per cent. From these the design of the heating surfaces can be determined.

**Some Recommendations on the Design of Natural Circulation Boilers for Steam of Very High Pressure and Temperature.** V. A. Loshkin and L. B. Krol'. *Teploenergetika* 1956 (11), 3-10, D.S.I.R. Translation CTS. No. 408.

Specific advice is given on the design and installation of the economizer, downcomers, furnace water walls and radiant and convection superheaters. Means of controlling the temperature of the superheated steam are discussed.

#### Fuel Firing

**Effects of Particle Size on Firing Pulverized Solid Fuels in Boilers.** A. L. Bayles. *A.S.M.E. Preprint* 57-A-276, 1957, (Dec.), 24 pp.

A discourse is presented based on theory and practical experience of the advisability of pulverizing coal to finer mesh sizes with a smaller percentage of oversize than used previously. By the adoption of such finer grinding the amount of excess air, fouling of heat transfer surfaces and the amount of combustibles in the fly ash would be considerably reduced. A comparison of a jet pulverizer with air as grinding medium and a conventional mechanical pulverizer shows that the overall operating costs of the jet pulverizer would be 15 cents/ton of coal with a fineness rating of 90 per cent through 200 mesh against 18.5 cents/ton of coal with a fineness of 70 per cent through 200 mesh.

**New Pulverized Coal Process Can Use Low-Grade Fuel.** Anon. *Coal Age* 1958, 79 (Jan. 18), 169.

The Attritor dryer pulverizer for coal-fired shell-type boilers developed by A. Herbert Ltd. and the installation in the new boilerhouse at the Lutterworth works are described. The coal is crushed on arrival to  $\frac{1}{2}$  in. and delivered to the bunkers from which it passes to an Attritor feeder. In an ascension tube from this feeder the coal is partially dried by hot flue gases and final drying and pulverizing takes place in the mill placed at the back of the boilers. In tests with slurry of 25 per cent moisture and 25 per cent ash content an evaporation of 11,000 lb/h was obtained on a Lancashire boiler.

**Stoker Operation.** L. J. Cohan. *COMBUSTION* 1958, 29 (Jan.), 51-5.

A survey is presented dealing with: (1) Size consideration; (2) Controls; (3) Coal and ash handling equipment; (4) Coal selection; (5) Stoker maintenance.

**New Concepts in Stoker Design.** F. C. Messaros and F. C. Belsak. *A.S.M.E. Preprint* 57-A-273, 1957, (Dec.), 10 pp.

The vibrating-grate stoker consists of longitudinal tubes forming part of the water circulation of the boiler embedded in cast-iron blocks carried by vertical flexible steel plates vibrated by a vibration generator; the spaces between the plates constitute air compartments. The grate is inclined 14 deg to ensure positive fuel travel. Notches in the block faces form tuyères for the admission of the air to the fuel. The furnace design has to be adapted to the stoker to obtain optimum results. Experience has shown that the stoker is able to burn efficiently a wide variety of fuels, to respond rapidly to load changes, to burn out the fuel completely and to create very little fly ash so that dust collection equipment is unnecessary.

**Development and Operating Experience of the Jet-Injection Stoker.** N. W. Young. *A.S.M.E. Preprint* 57-A-192, 1957 (Dec.), 8 pp.

The stoker is of the traveling-grate type with compartmented zones, a completely sealed front and without ignition arch but with air jets at a pressure of 10-20 in. w.g. at the front to create a highly turbulent zone for the combustion of the volatiles. The heat radiated from this high temperature combustion zone facilitates the ignition of the green fuel. The volume of air injected is about 6-10 per cent of the whole combustion air. The new design of the compartments pre-

vents leakage of air from one compartment to the next or between stoker and furnace walls. The stoker drive is infinitely variable from zero to full speed. The fuel should be  $1 \times 0$  in. with 20-60 per cent smaller than  $\frac{1}{4}$  in. It is stated that the amount of excess air is smaller (maximum 35 per cent), power consumption lower and combustibles in the ash less than with other types of stoker and no dust collection equipment is required.

#### Furnaces and Combustion

**Operational Success of Slagging Crucible Furnace.** F. Petrasch. *Mitt. V.G.B.* No. 51, 1957 (Dec.), 412-6. (*In German.*)

This special type of slagging furnace has been developed for firing coals with ash of high melting point since the shape given to the furnace produces a very high heat release in the slagging chamber. The ash softening point of the coal used is about 2280 F and the fusion point 2820 F. Difficulties were experienced by the shape, dimensions and position of the slag hole which had to be altered several times to obtain the optimum solution. Another difficulty arose from large permanent accumulation of slag from the hole toward the side walls where it reached a height of up to 55 in. Based on these experiences the design of the crucible furnace for a new boiler has been considerably altered. Partial loads down to 40 per cent of full load are possible with liquid slag removal and lower loads with dry ash removal. Ash retention is 82-87 per cent. Power consumption by the boiler auxiliaries is 5.3 kw/hr/ton of steam. The boiler availability has been over 6000 hr and deposit formation has been negligible.

**Gas-Side Tube Erosion in Horizontal Cyclones.** E. Goecke. *Mitt. V.G.B.* No. 51, 1957 (Dec.), 417-21. (*In German.*)

A boiler rated at 400 klb/h, 1200 psi and 975 F contained two 9 ft dia horizontal cyclones in which a very low volatile coal (8.5-10 per cent V.M.) of high ash content (25-30 per cent) and low ash fusion temperature (2375-2460 F, Leitz) was burnt. At first very high temperatures in the cyclone, secondary and tertiary furnaces led to severe fouling of the superheater causing excessive flue gas temperatures and abnormally high preheated air temperatures (1020 F) aggravated the conditions. The measures taken to reduce fouling included the installation of more cooling surfaces and additional soot blowers so that the air temperature was reduced to 755 F. After these measures

had been taken erosion of cyclone tubes occurred because the low volatile coal was not ignited and burnt sufficiently until it reached the tubes opposite the burner mouth. After many attempts, a new burner design was evolved which obviated tube erosion, the main measure being a reduction of the velocity of the coal-air mixture from 75 to 49 ft/sec.

**Gas-Side Tube Wastage in Boilers with Slagging Furnaces.** H. Hübel. *Mitt. V.G.B.* No. 51, 1957 (Dec.), 421-30. (*In German.*)

The power station of the Fürst Leopold-Baldur Colliery contains two boilers with crucible-type furnaces (100/130 klb/h, 1200 psi, 932 F), one boiler with vertical cyclone and one with two opposed horizontal cyclones, these two rated each at 225/280 klb/h, 1300 psi and 975 F. The boilers are supplied with the same coal (22-24 per cent ash, 8-10 per cent moisture, 2.5-3 per cent S), an ash fusion point of 2425 F in reducing atmosphere and a slag of low viscosity. The tubes in the hottest zone of the crucible furnaces not being lined with refractory mass showed, after 16,000 hours of operation, a high degree of corrosion and erosion, the tubes in the bottom protected by refractory showed considerably less damage. Corrosion is ascribed to lack of air, stratification and insufficient cooling of the crucible tip. Installation of tangent tubes, arrangement of an air curtain over the most exposed tubes, reduction of the exit velocity of the pulverized coal and finer grinding are the remedial measures proposed. In the vertical cyclone, damage mainly due to erosion was found after only 5800 hr operation. Responsible were insufficient and badly arranged studs on the tubes (including bad workmanship), stratification due to insufficient mixing of secondary air and coal and an excessive enveloping air volume. Remedial measures have now been completed including new and increased studs on all tubes, finer grinding of the coal and redesign of the burners. In the horizontal cyclone furnaces themselves neither corrosion nor erosion occurred, but a slight erosion of tubes in the impact wall opposite the cyclone mouth. Severe damage of tubes was found in the tube-platen superheater caused by a combination of corrosion (scale) and erosion (stratification) and excessive temperatures of the combustion gases. A redesign of the impact walls and slag screens to reduce the temperature of the gases at the entry into the superheater and their stratification and a cross-over of tubes of the superheater has brought the desired results.

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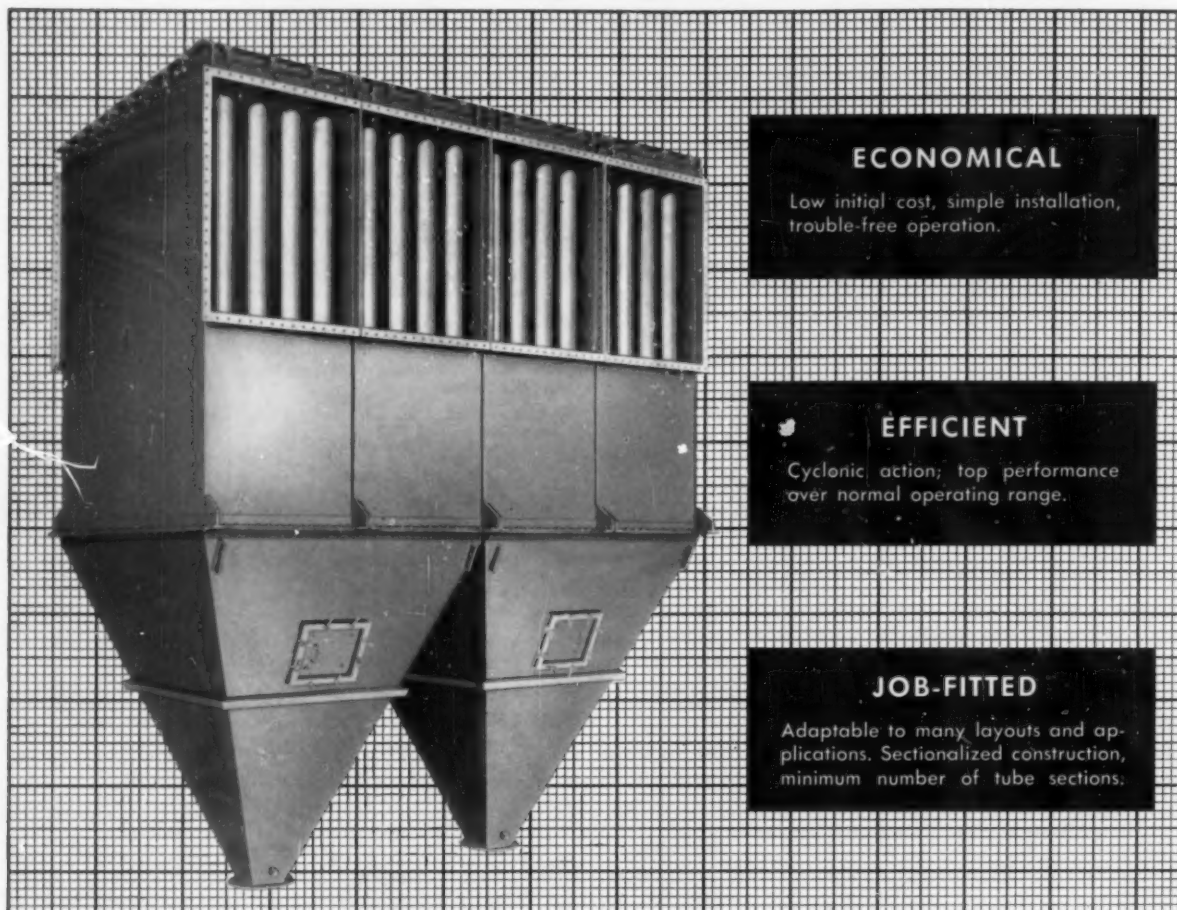
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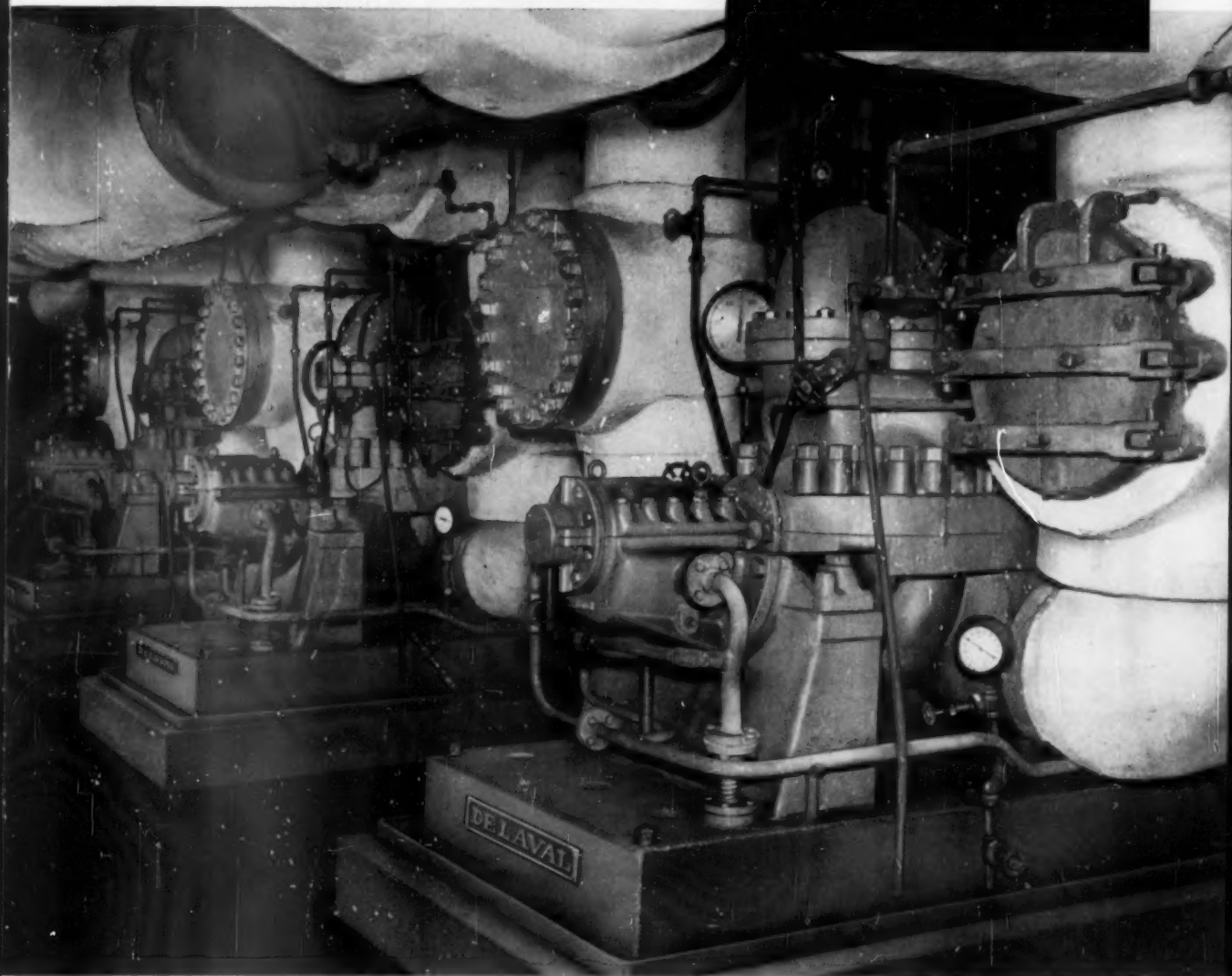
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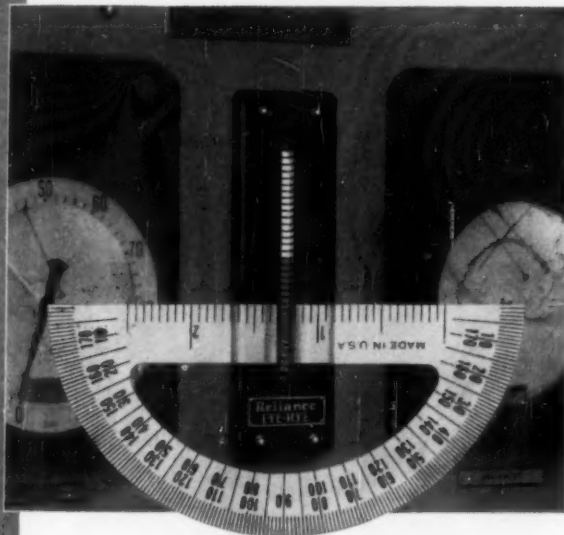
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This bulletin reports on intensive investigation into the problem of main steam piping materials and gives data on the stress rupture characteristics of Types 316 and 347 stainless steel piping adjacent to welded joints.

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